GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station

PROJECT INITIATION

Date: ~~July 16, 1973~~

Project Title: Develop High Intensity Electron Gun

Project No.: A-1558

Project Director: Dr. Raymond K. Hart

Sponsor: National Aeronautics and Space Administration

Effective July 1, 1973 . . . . Estimated to run until: December 31, 1973 . . . . . .

Type Agreement: Cost-Reimbursement Contract #NAS8-29860 . . . . Amount: $ . . 23,938 . . . .

REPORTS: Monthly, letter type
Final due December 31, 1973

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	Marshall Space Flight Center
	Alabama, 35812

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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date March 25, 1974

PROJECT TITLE: "Develop High Intensity Electron Gun"

PROJECT NO: A-1558

PROJECT DIRECTOR: Dr. Raymond K. Hart

SPONSOR: National Aeronautics and Space Administration

TERMINATION EFFECTIVE: February 28, 1974

CHARGES SHOULD CLEAR ACCOUNTING BY: All acceptable charges have cleared.

Final Report Delivered 2-27-74

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 6, 1973

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812
Attention: S&E-ASTR-IA/J. H. Kerr

Contract No: NAS8-29860

Georgia Tech No: A-1558

Subject: Develop a High Intensity Electron Gun;
Monthly Status Report No. 1 Covering the Period
July 1, 1973 through July 31, 1973

Dear Sir:

Work was commenced at the beginning of this reporting period to design an electron gun which will be compatible with the NASA owned Image Forming Light Modulator, constructed under Contract NAS8-27375. This electron gun is required to deliver a 2.5×10^{-3} cm spot on a target approximately 28 cm away from the cathode and have a current density of 2 amp cm^{-2}.

Technical Effort

The design of this high intensity electron gun is controlled by two parameters: these are the maximum practical demagnification of the source attainable with lens #1, and the minimum distance that lens #2 can be placed in front of the target (crystal). It was also considered that the most practical approach for this type of electron optical system is to use electrostatic lenses rather than electromagnetic lenses.

Consideration for Lens #1

Several requirements were set for lens #1. These were as follows:

a) The central electrode should be operated at cathode potential in order to avoid the necessity of an additional high voltage feed-through.

b) The lens elements and spacings had to be as small as possible since this lens must have a small focal length. Also, the image must be outside of the potential field of the lens in order to reduce distortions.

In order to arrive at suitable parameters both the lens data given by Grivet[1] and Haine[2] were investigated. It was found that these data gave essentially the same results, but since Haine's curves were a little easier to use, they were selected to make the final determination. Haine's curves are reproduced in Fig. 1.

After a number of combinations of S, T and D were considered, it was finally decided that the following lens geometry would be most suitable for the present application.

$a = 3.3$ cm, $a_1 = 0.6$ cm, $f = 0.48(0.5$ cm$)$, $C_s = 4.32$ cm, $S = 0.24$ cm,

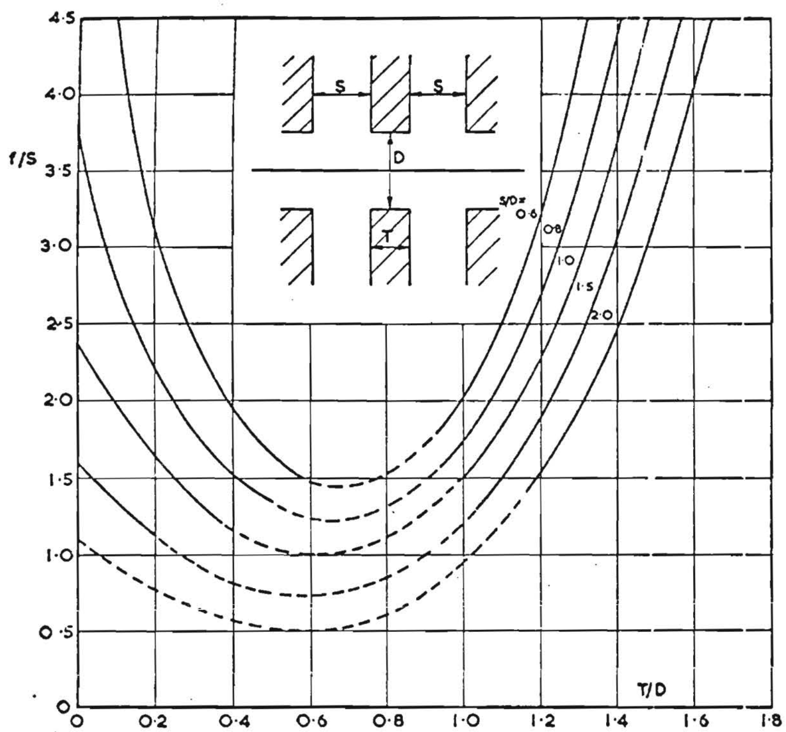
$T = 0.4$ cm and $D = 0.4$ cm.

<u>Consideration for Lens #2</u>

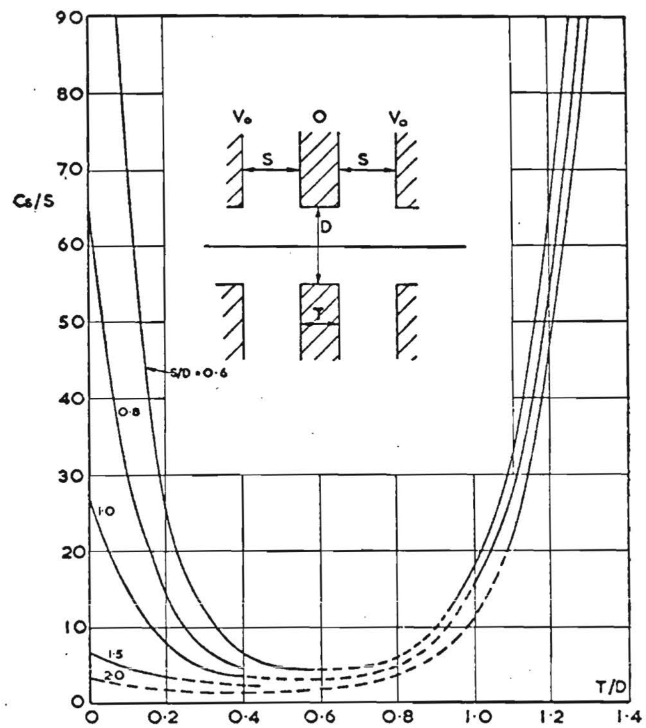
Since the purpose of this lens is to transfer the demagnified image of the source to the crystal, it can be treated as a weak transfer lens. Several requirements have to be met, however, which are to have as large an

(1) P. Grivet, "Electron Optics," Second English Edition, Pergamon Press, London, Page 573 (1972).

(2) M. E. Haine, "The Electron Microscope," E. & F. N. Spon, London, Page 21 (1961).



Focal properties of the three electrode Einzel lens as a function of its geometry.



Spherical aberration of the three electrode Einzel lens.

Fig. 1. Focal properties and spherical aberration of three electrode Einzel lenses with the center electrode operating at cathode voltage. Data taken from M. E. Haine, "The Electron Microscope," E. & F. N. Spon, London, page 21 (1961).

angular aperture as practical and for the center electrode to operate at as low a potential as possible. The large angular aperture allows maximum beam current to reach the target, while a low operating potential on the center electrode will ease the design.

Various combinations of thick and thin center electrodes as well as large and small bore diameters were evaluated. The most suitable compromise for the various lens parameters was met with the following:

$a = 11.7$ cm, $a^1 = 26.0$ cm, $f = 8.07$ cm, $C_s = 2874$ cm, $S = 0.5$ cm,

$T = 0.6$ cm and $D = 0.5$ cm.

The variation of focal length of lens #2 with electrode potential was calculated using the following expression

$$f = \frac{8}{3}\left(S + \frac{T}{2}\right)\left[\frac{1 + 2S/D - T/2D}{2SD}\right]^{2} \Big/ (1 - V_L/V_0)^2, \qquad (1)$$

where V_L is the center electrode voltage and V_0 the accelerating voltage. The results of these calculations are given in Fig. 2. Location of the various components along the electron pathlength are given in Fig. 3. As a check on the previous calculations, the final beam size can be determined for the parameters given in Fig. 3 by the following expression,

$$d_2 = \frac{q_2}{\left(\frac{D}{q_1} - 1\right)P_1} \cdot d_o, \qquad (2)$$

where d_o is the source size, q_1 is the image distance from first lens, q_2 is image distance from second lens, P_1 is distance from source to first lens and D is the distance separating the two lenses. By substitution, d_2 is

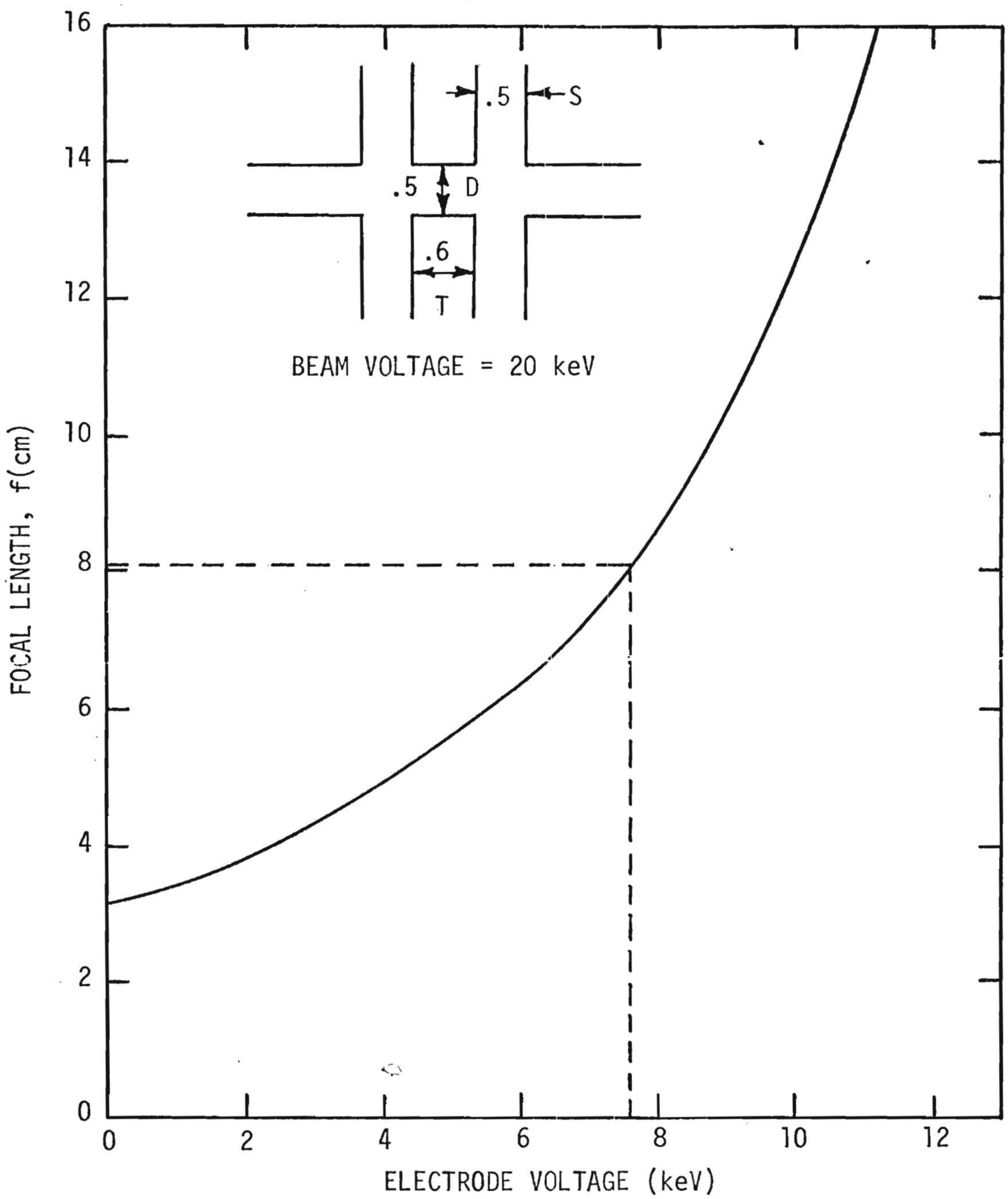
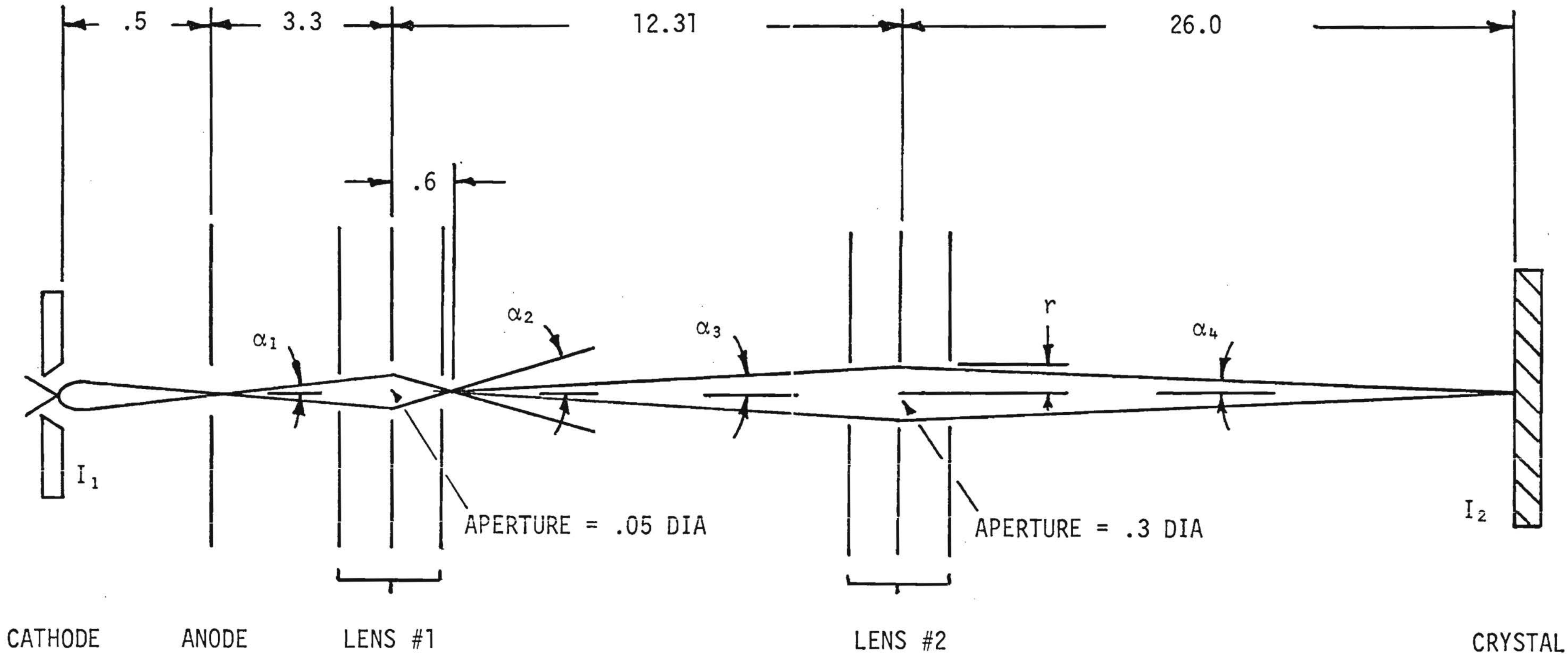


Fig. 2. Variation of focal length of Einzel lens, having the parameters shown in inset, with center electrode voltage. Values calculated using formula (1).



NOTE: Dimensions in cm

Fig. 3. Diagram showing the location of the major components along the electron pathlength.

calculated to be

$$2.02 \times 10^{-3} \text{ cm}(20.2 \text{ microns}).$$

Beam Intensity at Target

As the optical quality of the entire system is largely dependent on lens #1, the angular apertures were calculated which would give optimum resolution and optimum intensity. These values turn out to be 0.05 cm (500 μ) and 0.24 cm (2440 μ) respectively. Thus, providing there are no controlling factors from other parts of the optical column, the best compromise for the aperture size in lens #1 is between 0.05 and 0.24 cm diameter.

For the first approach to the problem, an aperture size of 0.076 cm was selected, since this size aperture is commonly used in the condenser lens systems of commercial electron microscopes.

With the aid of the following equation

$$I_2/I_1 = (rM_1)^2/(S\alpha_1)^2. \tag{3}$$

Values for beam current as a function of aperture size in lens #2 were calculated, and the results are given in Fig. 4. The results for a similar calculation using a 0.05 cm lens #1 aperture are also given.

If we now keep the aperture in lens #2 fixed and repeat the calculations for various aperture sizes in lens #1, the plot shown in Fig. 5 is obtained. Results using several values for lens #2 aperture are given in this figure. From these data it can readily be seen that a beam current of approximately 3×10^{-6} amp can be obtained in a 2.5×10^{-3} cm diameter beam (allowing for spread due to diffraction effects and lens aberrations) with apertures of

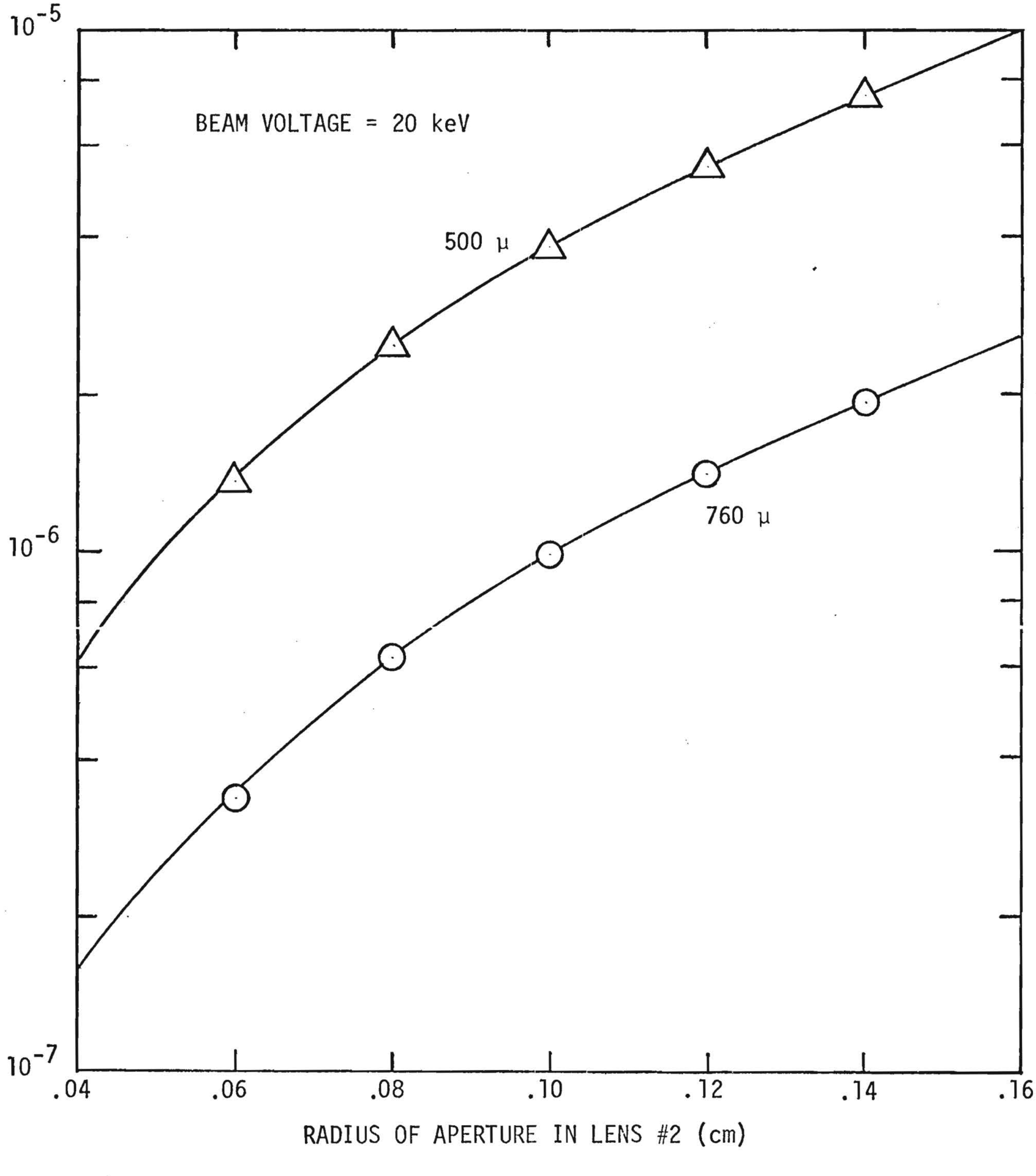


Fig. 4. Variation of probe current at the specimen with radius, r, of lens #2, for two sizes of lens #1 aperture, i.e., 500 μ and 760 μ diameter.

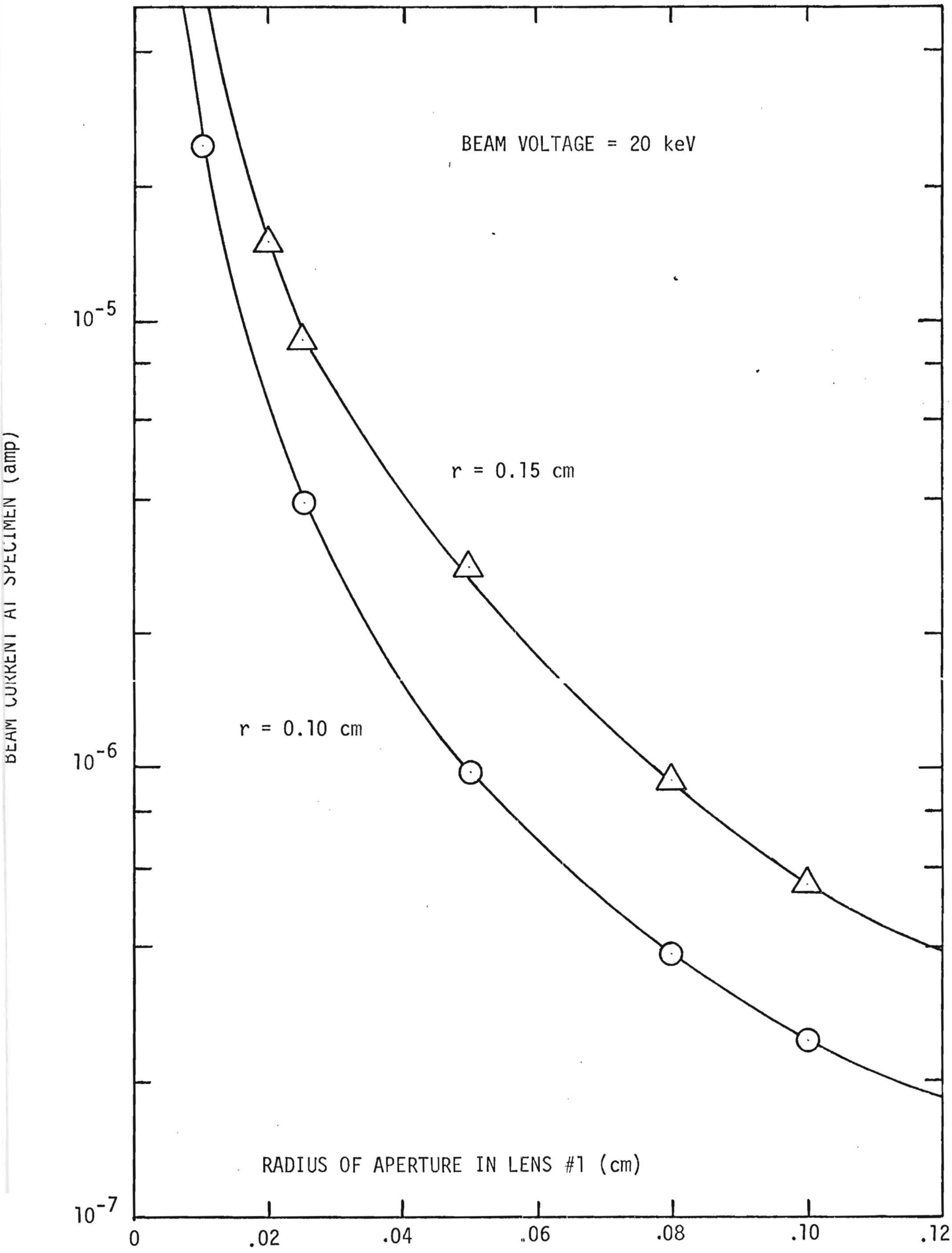


Fig. 5. Variation of probe current at the specimen with radius of lens #1 aperture, for two values of the aperture radius in lens #2.

0.05 cm and 0.3 cm dia in lens #1 and #2 respectively.

All the beam current calculations were made on the assumption that the beam current at the source (tungsten filament) would be 100 μA. This value of current is what one can expect from a reentrant type electron gun operating with the filament temperature between 2600 and 2700 °K. Over short periods of time the emission current of the gun can be increased by a factor of about 5, as shown in Fig. 6, but the filament lifetime would be drastically reduced. In Fig. 6, the lifetime data was taken from Grivet[(3)] while the electron emission data was calculated from the well known Richardson formula

$$I_s = AT^2 e^{-(b/T)} \tag{4}$$

and using values for A = 60.2 and b = 52,400 from Hall[(4)].

During the next reporting period it is expected that all the basic layout of the mechanical design will be completed and a start made on detailing components for fabrication in the machine shop. Most of the commercially available items that will be used in the construction of this electron gun have been ordered.

Work will also continue on the design and layout of electric circuitry which will be required to operate the electron gun.

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(3) P. Grivet, "Electron Optics," Second English Edition, Pergamon Press, London, Page 565 (1972).

(4) C. E. Hall, "Introduction to Electron Microscopy," McGraw-Hill, New York, Page 146 (1953).

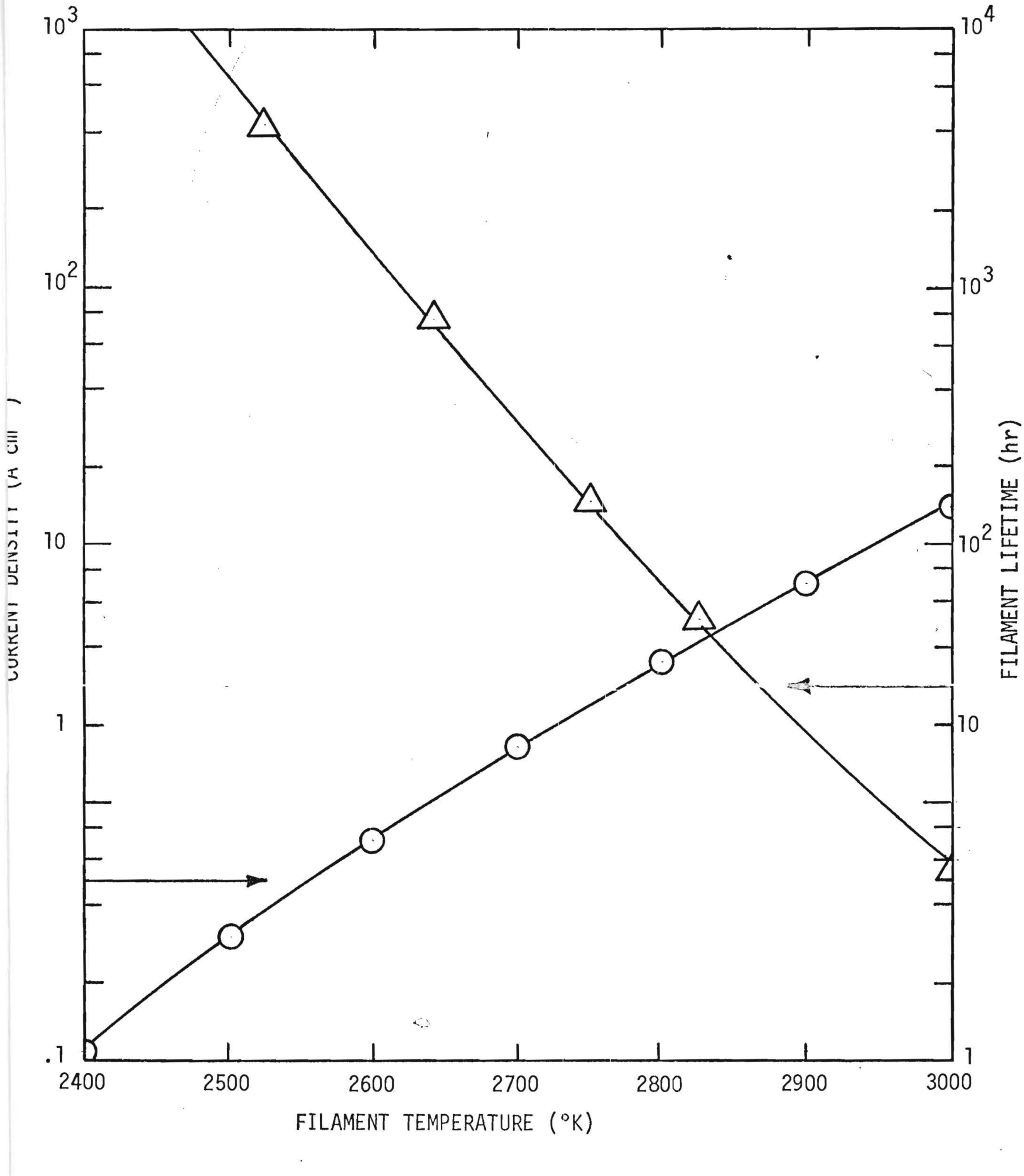


Fig. 6. Dependence of electron emission and filament lifetime on the operating temperature of a tungsten filament.

Monthly Status Report No. 1
August 6, 1973

Financial Data

A. Personal Services

	Man Hours	Cumulative Total
Project Director	134	134
Design Engineer	-	-
Support Personnel	8	8

B. Charges to Contract

Personal Services	$ 1,786.15
Materials and Supplies	0.00
Travel	0.00
Overhead	1,161.00
Retirement	0.00
Total Direct Charges	2,947.15
Encumbered Funds	145.84
	3,092.99
Total Budget for Contract	23,938.00
Total Funds Expended to Date	3,092.99
Free Balance	$20,845.01

The remaining funds should be sufficient to complete the contract.

Respectfully submitted

Raymond K. Hart

Raymond K. Hart
Project Director

RKH/jl

A-1558

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

September 10, 1973

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: S&E-ASTR-IA/J. H. Kerr

Contract No: NAS8-29860

Georgia Tech No: A-1558

Subject: Develop a High Intensity Electron Gun; Monthly Status Report No. 2 Covering the Period August 1, 1973 through August 31, 1973

Dear Sir:

The work carried out during this period and covered by this report consisted of the following items:

1. Completed the design considerations of the electron optical system.
2. Evaluated the parameters of the resistance network for controlling the focal length of lens #2.
3. Designed the stigmator control system.
4. Surveyed the market for items that can be used directly in this equipment, and purchased those we decided to use.

Design Considerations for Optical Column

The overall design concept has now been completed and is shown in Fig. 1. All the in-vacuum elements of the system are attached to an interior stainless steel tube, which bolts directly to the 6" conflat flange. Various electrical feedthroughs and electrical conductors are likewise attached to this flange.

Lens #2 is the pivot point for the entire column, i.e., it has a fixed position with respect to optical axis and distance to crystal.

Lens #1 is fixed in axial distance from both the gun and lens #2, but is moveable laterally by about ±0.1 cm. This degree of freedom will allow lens #1 to be aligned to the optical axis of lens #2. Once this lens has been bench aligned, it will be locked in position by four set screws.

Both the anode and defining aperture of lens #1 can be removed from their respective positions in lens #1 without removing the lens from the inner support tube. It will be necessary to remove the filament and wehnelt cylinder assembly in order to remove these two components. The filament assembly would normally be removed for a general column cleanup, so this poses no problem.

An appreciable part of this report period was used up in considering various ways in which the filament assembly could be removed from its operating position without disassembly of the optics tube from the 6" conflat flange. In addition, a mechanism had to be devised so that the filament assembly could be centered on the optical axis, and with a driving mechanism that can be easily disengaged.

These requirements posed some interesting problems, however, we have come up with what appears to be a practical solution.

The whole cathode assembly, except for the base plate that is bolted to the terminal bushings, and the base plate retaining ring are free to move about ±0.1 cm. It is spring loaded through the biasing voltage connector and works against two 120° opposed drive mechanisms. These mechanisms are bellows sealed and can be withdrawn sufficiently far as to clear the inner drive mechanism, which is part of the optical support tube. Since these linear drives have to be insulated for 20 keV, we are transmitting the lateral movement by means of two sapphire rods, 1 inch long by 1/4 inch in diameter.

In order to use the purchased filament assembly without modification, we resorted to an interfacing collar, which slides in a rectangular groove and the whole sub-assembly (filament, wehnelt shield and interfacing collar) is held in the cathode assembly with a retaining clip. A large rectangular hole in the wall of the support tube will allow access for direct replacement of filaments.

Focus Control

The high voltage wiring circuit for the active optical elements is shown in Fig. 2. Variable controls are only required on two elements, i.e., the biasing voltage to the wehnolt shield and the voltage to the control electrode of lens #2.

Details of the resistance network for focussing control of lens #2 are shown in Fig. 3. The magnitudes of the coarse (±1000 V) and fine (±500 V) voltage controls should be ample to meet the design specifications.

Stigmator Control System

The wiring diagram for the stigmator in lens #1 is shown in Fig. 4. This circuit is essentially the same as one that has been used on a number of other electrostatically compensated lens systems and is known to operate quite adequately.

The stigmator itself is a hexapole system with beryllium copper pins in a teflon bushing. The diametrical separation of the pin faces is 0.4 cm.

Purchasing of Materials

An item of such specialized equipment will naturally require items of equipment and materials that are not readily available. This electron gun is no exception.

Although stainless steel will be used whenever possible in this electron gun's construction, we will have to use dissimilar metal on some mating parts. In most cases beryllium copper will be used. A 3 1/4" dia by 12" long billet of titanium--6% aluminum--4% vanadium has been purchased for construction of the two lenses. This alloy has better electrical properties than stainless steel, especially when used in very strong electric fields.

All the electrical feedthroughs are now on hand. Some difficulty was experienced in locating a high voltage feedthrough to handle 8 keV and which also contained a suitable cable connector.

Four special potentiometers are required for the associated electrical circuits. One of these is a sin/cos potentiometer for changing the phase at the stigmator pins. The other three potentiometers are high megohm units which also have to withstand high voltage (about 5000 V) between each pair of terminals. Sources have been located and the four potentiometers are now on order.

The program for the next interval will be to detail the mechanical design and to start fabricating the various components in the Georgia Tech machine shop.

The interfacing of the electron gun electronics with the existing electronics of the electro-optical modulator will be discussed with members of the Electronics Division. Construction will commence as soon as technical help is available.

Financial Data

A. Personal Services

	Man Hours	Cumulative Total
Project Director	101	235
Design Engineer	182	182
Support Personnel	28	36

B. Charges to Contract

Personal Services	$ 2,701.90
Materials and Supplies	205.24
Travel	0.00
Overhead	1,756.24
Retirement	151.82
Total Direct Charges	4,815.20
Encumbered Funds	781.21
	5,596.41
Total Budget for Contract	23,938.00
Total Funds Expended to Date	8,689.40
Free Balance	$ 15,248.60

The remaining funds should be sufficient to complete the contract.

Respectfully submitted,

Raymond K. Hart
Project Director

RKH/jl

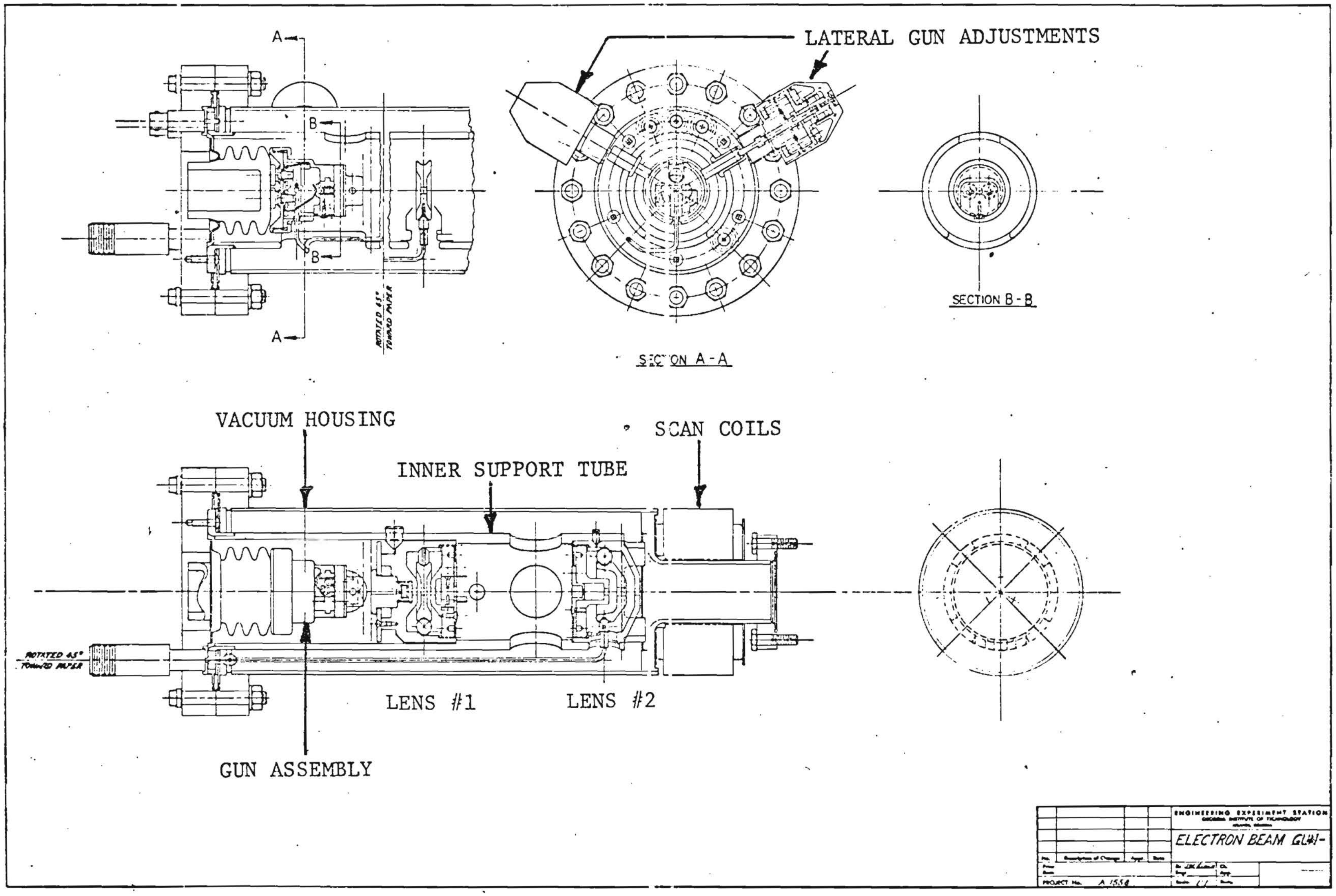
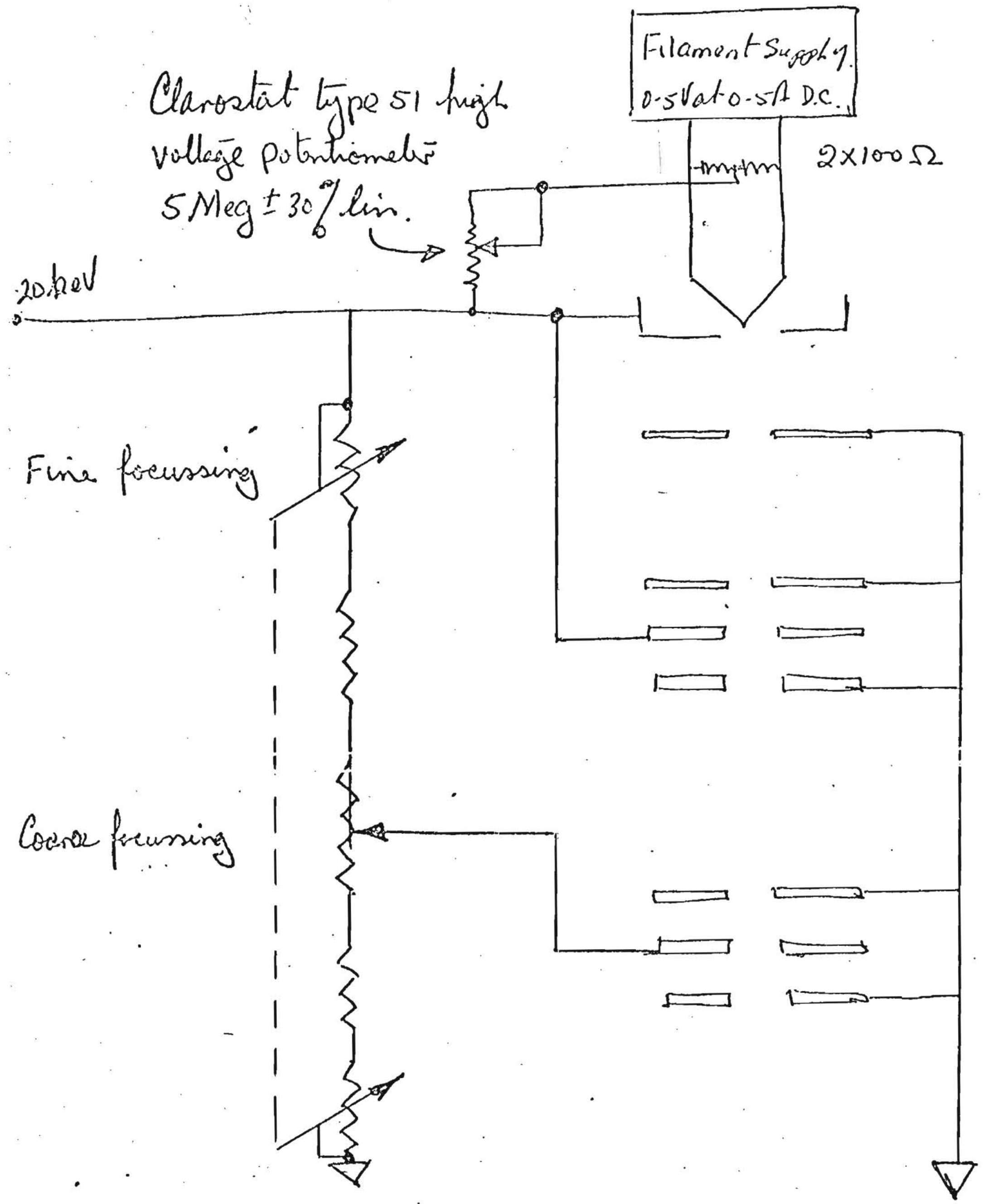
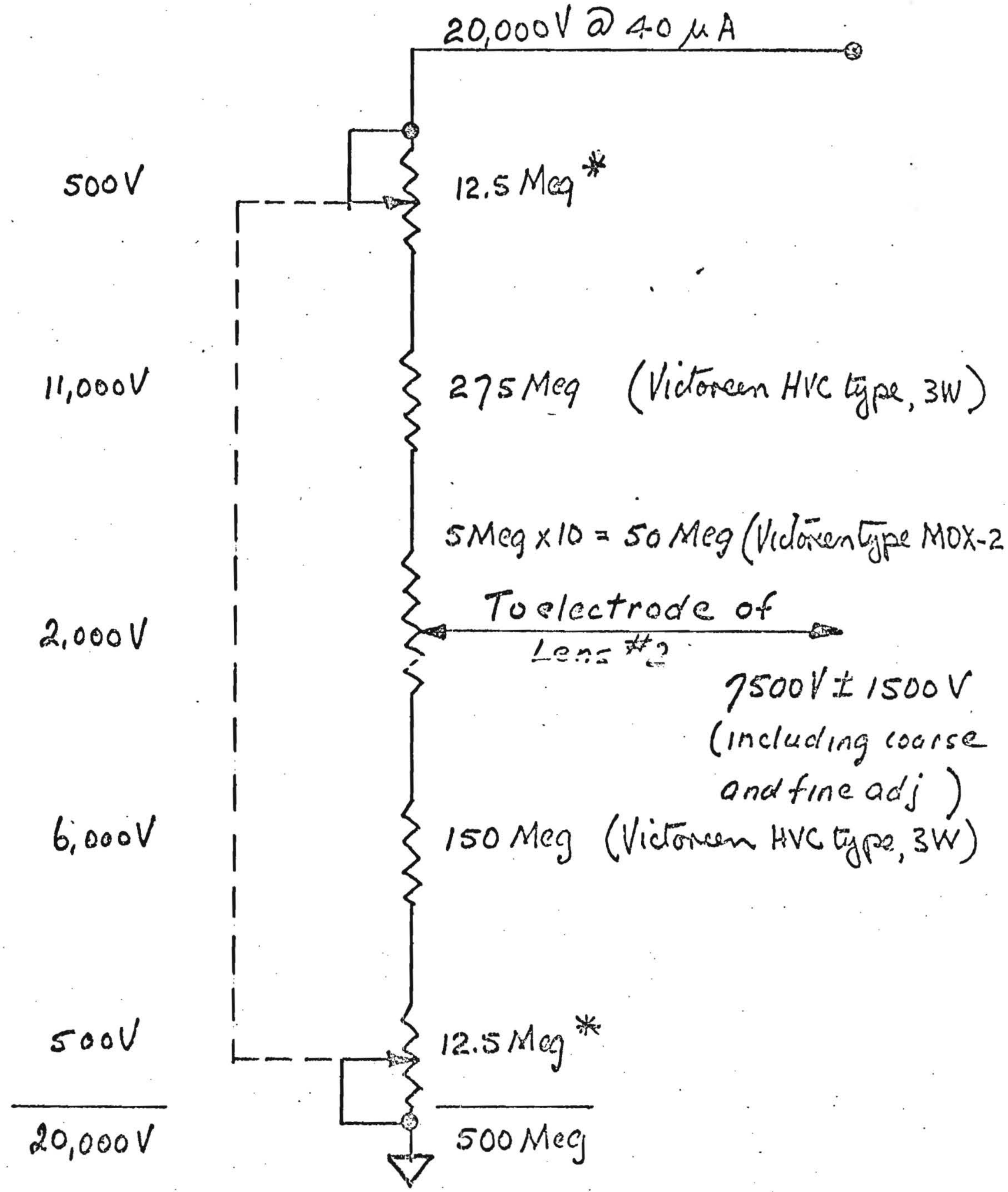


Fig. 1. Diagram of entire electron optical column and several sectional views showing details of electron gun traversing mechanism.



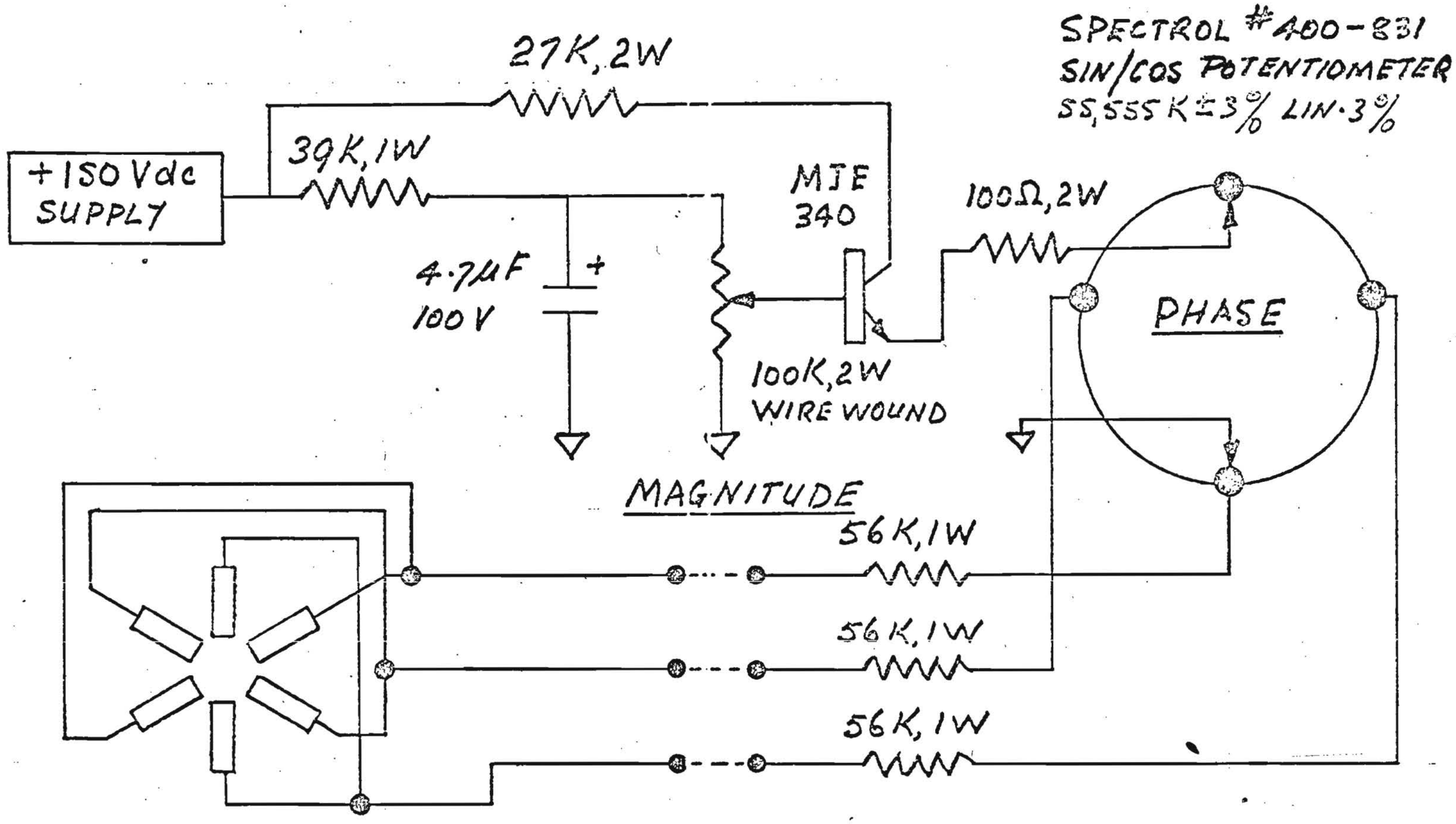
Total resistance in focussing resistance leg is set at 500 Meg, which will draw 40 μA current and 0.8 watt power.

Fig. 2. Schematic of the high voltage connections for the electron gun.



* The fine adjustment consists of two Clarostat type 51 high voltage potentiometers which are ganged together. Each is 25 Meg ± 30% lin and are designed to operate about their midpoints.

Fig. 3. Resistance network to control lens #2.



STIGMATOR CONTROL

Fig. 4. Circuit diagram for the electrostatic stigmator for compensating lens #1.

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

October 10, 1973

National Aeronautics and Space Administration
Geprge C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: S&E-ASTR-IA/J. H. Kerr

Contract No: NAS8-29860

Georgia Tech No: A-1558

Subject: Develop a High Intensity Electron Gun; Monthly Status Report No. 3 Covering the Period September 1, 1973 through September 30, 1973

Dear Sir:

There are three items of significance to report in regard to the work accomplished during this past month's effort. These items are a) the machine shop started working on detailed gun components, b) the remainder of the material for fabricating the gun was placed on order and c) discussions were held on ways to modulate the beam at 4 MHz.

At the time of writing this report about half of the electron gun components had been detailed, and we are forwarding these drawings to a machinist in our central machine shop who is now working full time on this project. There is still one item associated with the gun itself to be designed, and that is the beam deflection system; discussed later in this report. The gun control module still has to be designed and alterations to the video amplifier also have to be made.

All the metal stock for this project has now been placed on order, and we are hoping to have it within the next week or so. We experienced some difficulty in locating suitable sources for some of the specialized materials that we called for in the drawings. To complicate matters as well as to cause a considerable delay, the order was sent out for bids by our Procurement people. Only one bid was received and then the bidder only bid on about half the items. Other sources have been found for the remainder of the items.

A more serious problem that we have run into is the beam modulating system. This was discussed at length with Joe Walsh in Electronics, who was responsible for the original design under NASA Contract NAS8-27375.

During the design stages of the present electron gun it had not been realized that the voltage available to modulate grid #1 was only about 70 volts. As it turns out, to modulate the beam in the new gun by means of the Wehnelt shield (the equivalent to G_1 in the old system) is not possible for several reasons. These are: a) the Wehnelt shield is a reentrant type so no beam cutoff is possible, b) the biasing voltage in the new gun is about 200 volts, which makes the existing video amplifier with a 70 volt output completely inadequate, and c) the capacitance of the new gun assembly will be many pF, even if the amplifier was mounted directly on top of the high voltage insulator.

As a result of these difficulties we have decided to modulate the beam intensity by means of an electrostatic deflection system, which will be located between lenses 1 and 2. This solution is not without its problems.

Since the between lens position is the only one available to accommodate the deflectors in the present design, we have been forced to locate the deflector plates about a diverging beam. It is preferred to work with a converging beam, since under these conditions the blanking aperture, over which the beam is being swept, can be kept to a minimum. This means that the amplifier drive level can also be kept low.

Calculations show that 4 cm long deflection plates separated by 0.6 cm will require plus and minus 180 volts to deflect a 20 keV electron beam through 0.218 cm, i.e., 0.026 rad. This is the angular aperture required by lens #2 in order to maintain optimum beam intensity.

It is proposed to use four deflection plates instead of only the two required for beam modulation. With the four-plate arrangement we will be able to trim the beam alignment with d.c. voltages on the plates. A mini four-pin feedthrough will be added to the vacuum wall adjacent to the deflection system. This feedthrough will have to be removed from the housing before the electron optical assembly can be removed for filament change etc.

The program for the next interval will be to complete the mechanical design and drafting and to continue the fabrication of components. It is anticipated that a start will be made on the electron gun control package. We should also be in a position to check out some of the fabricated items.

Financial Data

A. Personal Services

	Man Hours	Cumulative Total
Project Director	53	288
Design Engineer	159.5	341.5
Support Personnel	24	60

B. Charges to Contract

Personal Services	$2,043.69
Materials and Supplies	0.00
Travel	0.00
Overhead	1,328.40
Retirement	110.54
	3,482.63
Encumbered Funds	0.00
	3,482.63
Total Budget for Contract	23,938.00
Total Funds Expended to Date	12,172.03
Free Balance	$11,765.97

The remaining funds should be sufficient to complete the contract.

Respectfully submitted,

Raymond K. Hart
Project Director

RKH/jl

A-1558

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 14, 1973

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: S&E-ASTR-IA/J. H. Kerr

Contract No: NAS8-29860

Georgia Tech No: A-1558

Subject: Develop a High Intensity Electron Gun; Monthly Status Report No. 4 Covering the Period October 1, 1973 through October 31, 1973.

Dear Sir:

During this reporting period work has continued on the following items:

1) Detailing engineering drawings and fabricating components.

2) Design of gun control module and procurement of components.

3) Detailing beam modulating system and purchasing the additional hardware required for this system.

All the major components of the electron gun have now been detailed. The remaining items to be detailed are aperture holders and the controls for moving the filament assembly in the X-7 plane with respect to the beam axis. This work has been delayed because of the effort that has been put into the design of a suitable beam modulating system.

Both the electrostatic electron lenses have been fabricated, although the final polishing of the critical areas of these lenses has not yet been done. Items of this nature will be done at one time, i.e., during the final fitting, cleaning and assembling of all the gun components.

The metal stock for the vacuum housing has been delivered and work is in progress to complete this unit. As soon as this is done, we will be able to vacuum test all the exterior welding for possible leaks.

The gun control module has been designed and all the component parts are either ordered or on hand. We have not taken delivery of the main chassis, and until that arrives, we will not be able to start the final construction.

In the final assembly, all the high voltage cabling (RG8/U) will plug into the control by means of special plugs, which we have fabricated in our shops. The advantage of this arrangement is that the interconnecting cabling can rapidly be disconnected for packaging and transport of the unit, and it will also facilitate trouble shooting. We propose to supply 10 ft long high voltage leads.

The controls that will be located on the supply module will be the following: heating and intensity for the filament; coarse and fine focus adjustment for lens #2; magnitude and phase adjustment for astigmatism in lens #1. All these will be on a 10-1/2 in high standard relay rack panel.

A general assembly view of the electron gun system showing the beam deflecting system, A, located in the optical column is shown in Fig. 1. It should be pointed out that this deflecting system does not alter the optical properties of the focussed beam on the crystal target. All it does is deflect the beam out of the defining aperture, B, at the modulating frequency, which is applied to the deflection plates.

Figure 2 gives a more detailed layout of the deflection system. It has been designed so that apertures can be removed for cleaning without the removal of major optical components, such as lenses, from the main support housing. Also, to remove the optical column from the vacuum housing in order to change the filament, etc. requires the removal of one additional item, and that is the four conductor mini-conflat feedthrough in the vacuum housing.

The work intended for the next reporting period will consist of assembling and testing the fabricated items, especially in regard to vacuum compatibility and high voltage breakdown. Work will also commence on assembling the gun control system. This unit, of course, will be needed to check out the electrical and optical properties of the optical column components and then the final assembly.

We anticipate that the remaining fabrication of components and their testing will proceed in a manner which will allow us to meet the delivery date set by the contract. It must be realized, however, that this electron gun is an experimental unit which is being developed on a very tight schedule. In being such a unit there are naturally a number of unknown factors, any of which could give problems in the final testing.

The total compatibility of this electron gun with the existing Image Forming Light Modulator (IFLM) will depend on the beam modulating electronics, which are part of the existing IFLM.

Financial Data

A. Personal Services

	Man Hours	Cumulative Total
Project Director	48	336
Design Engineer	160	501.5
Support Personnel	241	301

B. Charges to Contract

Personal Services	$ 2,931.00
Materials and Supplies	894.05
Travel	0.00
Overhead	1,905.15
Retirement	69.32
	5,799.52
Encumbered Funds	23.25
	5,822.77
Total Budget for Contract	23,938.00
Total Funds Expended to Date	17,994.80
Free Balance	$ 5,943.20

The remaining funds should be sufficient to complete the contract.

Respectfully submitted,

Raymond K. Hart
Project Director

RKH/jl

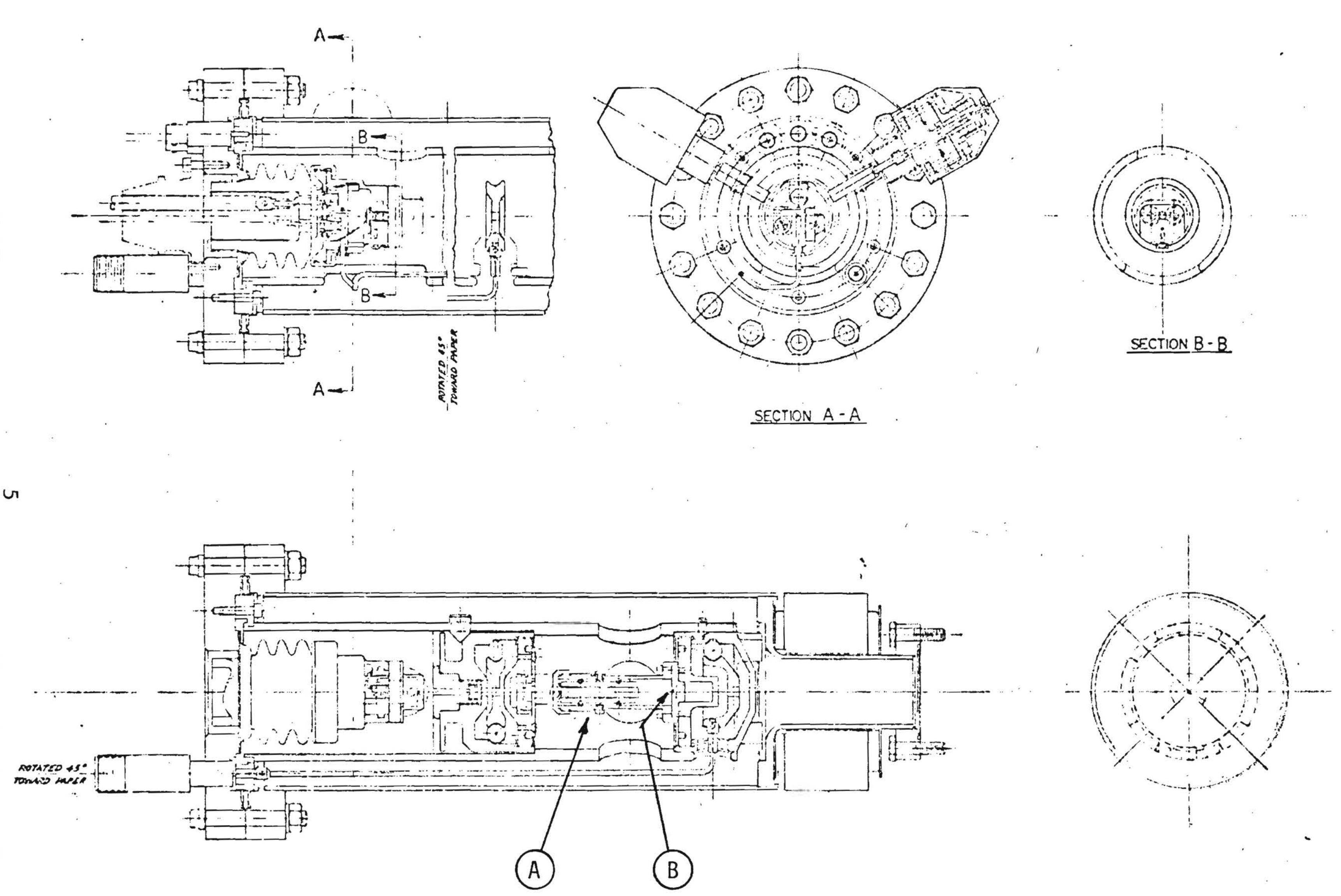


Fig. 1. Modified general assembly view of electron gun system showing beam deflecting system in place.

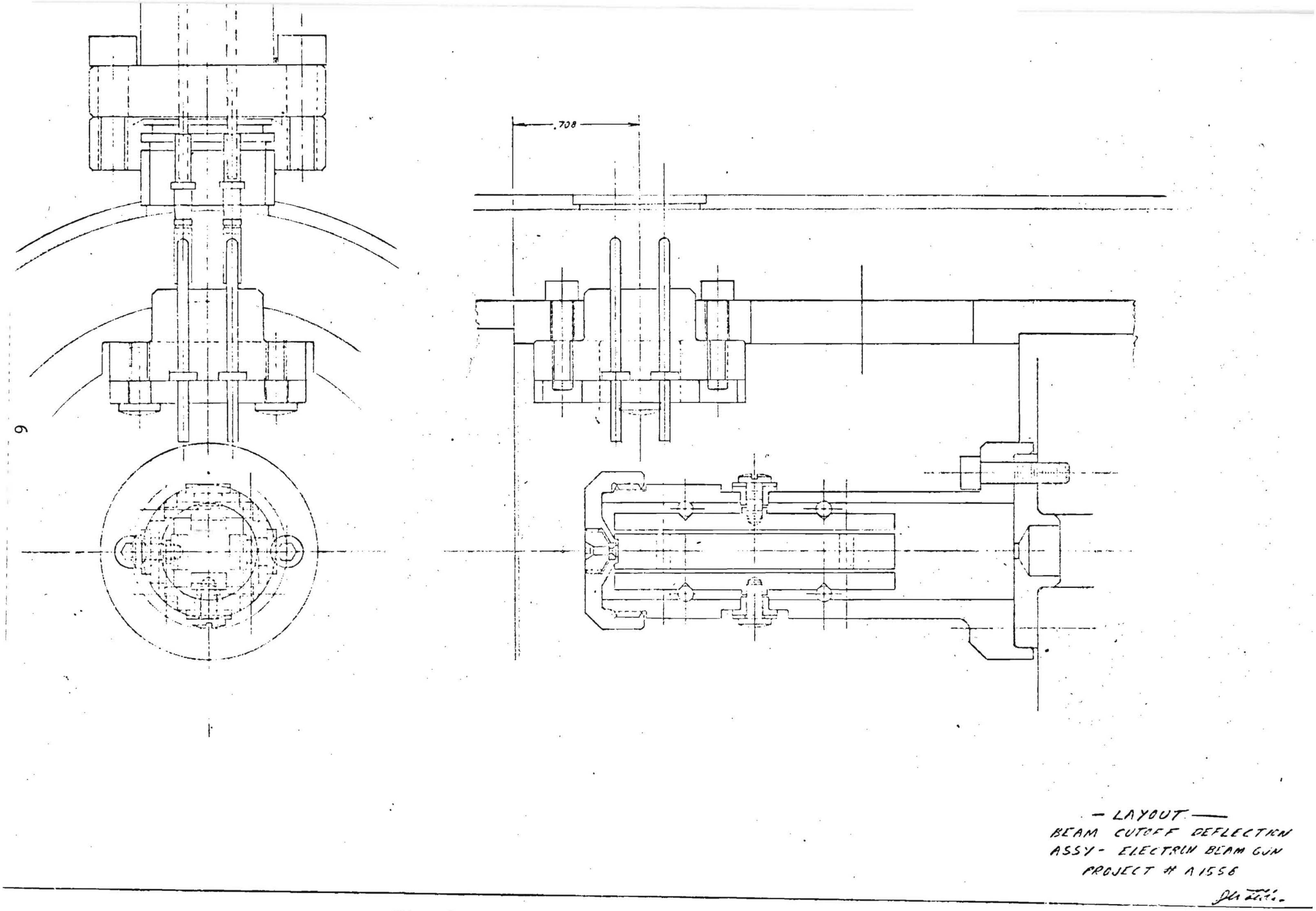


Fig. 2. Detailed layout of beam deflecting system.

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

December 10, 1973

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: S&E-ASTR-1A/J. H. Kerr

Contract No: NAS8-29860

Georgia Tech No: A-1558

Subject: Develop a High Intensity Electron Gun; Monthly Status Report No. 5 Covering the Period November 1, 1973 through November 30, 1973.

Dear Sir:

During this reporting period work has continued on the following items:

1) Detailing remaining gun components.

2) Fabricating of detailed components.

3) Complete fabrication of gun control module.

Because of the delay caused by design considerations related to the beam modulating system, a number of minor electron gun components were not detailed in the last reporting period. It was hoped to have all components detailed at the time of this writing, but alas, there is still several more weeks' work required before all drafting will be complete.

The thoroughness with which we have conducted the design concept has enabled the shops to fabricate components with no rejects, so we have been able to assemble and final test components as they become available.

At the time of writing this report we have all the major items of the contracted item complete. The gun control module and the interconnecting cabling have been completed and bench tested. We still have to take delivery of the high voltage plug which we expect in about one week's time. Except for this item all the basic gun control systems have checked out satisfactorily at 20 keV. We expect no problem from the high voltage plug. The electron lenses still have to be checked out for electrical breakdown, and we are in the process of checking out these items.

Except for the welding together of the X-Y manipulators for cathode alignment, all the outer vacuum housing is complete. Vacuum testing has not been possible without the alignment controls, which are currently being welded. As soon as these units are returned from the welder we will vacuum test the outer housing.

The fabrication of the cathode assembly is well underway and we should be able to assemble this unit within the next week.

Assuming no unforeseen difficulties are encountered the basic gun assembly which will produce a beam of required dimensions should be ready for testing within the next week or two. Should it meet specifications, it will be transferred to the IFLM for further testing. Hopefully its performance will meet the design criteria and the subject equipment will be accepted as partial fulfillment of the contract. The final report is also receiving our attention.

Financial Data

A. Personal Services

	Man Hours	Cumulative Totel
Project Director	42	378
Design Engineer	160	662
Support Personnel	158	459

B. Charges to Contract

Personal Services	$ 2,553.70
Materials and Supplies	258.41
Travel	0.00
Overhead	1,659.91
Retirement	144.42
	4,616.44
Encumbered	- 61.43
	4,555.01
Total Budget for Contract	23,938.00
Total Funds Expended to Date	22,549.81
Free Balance	$ 1,388.19

Respectfully submitted,

Raymond K. Hart
Project Director

RKH/jl

DEVELOP HIGH INTENSITY ELECTRON GUN

FINAL REPORT
PROJECT NO. A–1558

by
R. K. HART
RESEARCH CONTRACT NAS8–29860

Performed for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

1 July 1973 to 31 December 1973

1973

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

FINAL REPORT

PROJECT NO. A-1558

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RAYMOND K. HART

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ABSTRACT

This report describes the development of an experimental high intensity electron gun for 20 keV operation. Its specific purpose is as a write gun in an experimental image forming light modulator (IFLM), which was previously developed under Contract No. NAS8-27375, June 1972.

In the IFLM system the write beam is required to deliver information to the light modulating KD^*P crystal at regular TV scan rates. Also, the electron beam intensity must be sufficiently large as to produce sufficient electric charge at each image point on the crystal, so as to allow the electro-optic Pockel's effect to be employed to modulate the light beam. The electron gun was designed to deliver a beam current density of 2A cm^{-2} at the crystal target, which is situated 42 cm from the cathode. In order to obtain a spatial resolution in the video image on the crystal comparable to that obtained in commercial TV images, the gun optics were designed to produce a focussed spot of 2.5×10^{-3} cm (.001 in) on the crystal. The electron raster on the crystal is 5 x 5 cm.

The entire electron-optical column is assembled on one six inch flange so that it can readily be withdrawn from its vacuum housing for filament changes, cleaning etc. All materials used in the construction of this electron gun are ultrahigh vacuum compatible, enabling the system to operate in pressures of $< 10^{-9}$ torr. This contamination-free environment permits the use of electrostatic lenses, which in turn led to a very compact, lightweight instrument.

TABLE OF CONTENTS

		Page
I.	INTRODUCTION.	1
II.	THEORETICAL CONSIDERATIONS.	4
	A. Symbols used in Text.	4
	B. Electron Source	5
	C. Electrostatic Lenses.	9
	1. Considerations for Lens No. 1	9
	2. Considerations for Lens No. 2	10
	D. Beam Intensity at Target.	12
	E. Beam Modulation	15
III.	GENERAL CONSTRUCTION.	20
	A. Optical Column.	20
	1. Cathode Assembly.	23
	2. Electrostatic Lenses.	26
	3. Beam Modulator.	29
	B. Vacuum Housing.	29
	1. Magnetic Shielding.	30
	C. Beam Deflection Coils	30
	D. Electron Gun Control Module	32
IV.	OPERATING PROCEDURE	39
	A. Column Alignment.	39
	B. Operating Conditions.	40
	C. Dismantling the System.	41
V.	PERFORMANCE OF THE ELECTRON GUN	44

TABLE OF CONTENTS (CONTINUED)

	Page
VI. MAINTENANCE OF ELECTRON OPTICAL COLUMN.	48
A. General	48
1. Final Cleaning of Gun Component Parts	48
B. Filament Replacement.	49
C. Aperture Replacement.	50
1. Anode Aperture.	50
2. Modulator Aperture.	50
3. Lens No. 2. Aperture.	51
VII. CONCLUSION AND RECOMMENDATIONS.	52
VIII. ACKNOWLEDGEMENTS.	54
IX. REFERENCES.	55
X. APPENDIX.	56

LIST OF FIGURES

Page

1. Performance of several cathode gun designs, with cathode aperture of 0.12 cm diameter and high voltage at 50 keV- after Haine and Einstein, ref (1). 6

2. Dependence of electron emission and filament lifetime on the operating temperature of a tungsten filament 8

3. Focal properties and spherical aberration of three electrode einzel lenses with the center electrode operating at cathode voltage. Data taken from M. E. Haine, ref (5) 11

4. Variation of focal length of einzel lens, having the parameters shown inset, with center electrode voltage. Values calculated using formula (2) 13

5. Diagram showing the location of the major components along the electron path. 14

6. Variation of probe current at the specimen with radius, r, of lens #2, for two sizes of lens #1 aperture, i.e., 500 μ and 760 μ. 16

7. Variation of probe current at the speciment with radius of lens #1 aperture, for two values of the aperture radius in lens #2. 17

8. a. General Assembly Diagram of the complete electron gun. . . 21
   b. Assembly diagrams of the cathode showing details of the external centering mechanism 22

9. View of electron optical column with the vacuum housing removed. 24

10. Exploded view of lens tube, lenses and vacuum housing. 25

11. Plan view of lens No. 1 with screw-on electrode removed. This view shows method of insulating center electrode from lens housing 27

12. Oblique view of lenses Nos. 1 and 2, showing ball retaining strips and screws. 28

13. Wiring diagram for beam deflection coils 31

14. Front panel view of gun control module 33

LIST OF FIGURES (CONTINUED)

Page

15. Plan view of gun control module, showing layout of components. 34

16. Plug layout at rear of gun control module 35

17. Wiring diagram for circuits used in gun control unit. 36

LIST OF TABLES

I. Characteristics of Electron Sources Currently Used in Electron Optical Instrumentation. 3

II. List of Components for Electron Gun Control Unit. 37

I. INTRODUCTION

The purpose of this work was to develop an electron gun which will deliver a coherent beam of electrons onto a target-crystal in electro-optical devices and which will meet specific requirements as to beam size, current-density, scan rate and modulation frequency.

This gun will be used in the Image Forming Light Modulator which was developed at Georgia Institute of Technology for NASA under Contract No. NAS8-27375. In this electro-optical system, the write electron gun is required to deliver a coherent electron beam focussed to 2.5×10^{-3} cm diameter on a potassium dihydrogen phosphate (KDP) crystal located 42 cm down the beam axis from the cathode. The current density in the focussed beam is required to be equal to, or greater than, 2 Acm^{-2} at the target and will be driven to raster a 5 x 5 cm area on the crystal at the commercial TV rate while being modulated at 4 MHz.

Although the beam size, write speed and modulation are well within the state-of-the art, it is not such a simple matter to obtain beam current densities of the order of 2 Acm^{-2} at the target, especially when it is situated about 20 cm from the final lens. It will be noted that this current density is similar in magnitude to the emission current density of a thermionically emitting tungsten cathode, when operated under conditions for long service life. Since high beam currents may only be required for short periods of time (e.g., $<$ 1 min), it is possible to increase the emission current density by one to one and a half orders of magnitude by simply heating the filament to about 3100 °K. It must be realized that this can only be done with the sacrifice of filament life, which could be reduced under such circumstances to as little as one hour.

There are of course other options for obtaining high emission current densities. Currently available in electron optical instrumentation are lanthanum hexaboride cathodes ($\sim$ 20 Acm^{-2}) and tungsten field emission cathodes ($\sim$ 1000 Acm^{-2}). The various parameters for these two sources, together with those of a thermionically emitting tungsten cathode, are given in Table I. Future development of very high intensity electron beams will probably be centered around lanthanum hexaboride cathodes since these are more stable and easier to control than field emitting cathodes. However, because of the nature of the present program it was not possible to consider the more exotic types of electron sources.

This contract called for an electron gun to be designed specifically for operating in the existing IFLM equipment. The design parameters of this high intensity electron gun were controlled by two features: these are the maximum practical demagnification of the source (about 5×10^{-3} cm) attainable with condensing lens #1, and the minimum distance that the probe forming lens #2 can be placed in front of the target (crystal). It was also considered that the most practical approach for the optics of this gun was to use electrostatic lenses rather than electromagnetic lenses.

Fitting this electron gun into a package which is compatible in size to the existing IFLM was no small task. The result, however, is a very compact electron gun for 20 keV operation, and which contains several innovative features in lens design and external beam alignment during gun operation.

Table I. Electron Sources Currently Used in Electron Optical Instrumentation

Source	Physical Dimension of Source (angstroms)	Minimum Beam Diameter at Specimen (angstroms)	Brightness (amp/cm^2/ sterad.)	Source Temp. (°K)	Operating Pressure (torr)	Source Life (hours)
Tungsten Filament	1.3×10^6	~50	1.5×10^5	2700	$<10^{-4}$	~30
LaB_6-Shottky Emission	10^4	~25	2×10^6	<2000	$\sim 10^{-6}$	>100
Tungsten Field-Emission	$<10^3$	<10 (transmission)	8×10^9	ambient	$<10^{-9}$	$>>10^3$ (reconditioning necessary)

$$\beta = \frac{JeV}{\pi KT}\,\Omega\,\exp\left(-\frac{r^2}{M^2a^2}\right) \text{ - thermionic } (J = 120T^2\exp(-\phi/kT))$$

$$\beta = \frac{JeV}{\pi d}\,\Omega\,\exp\left(-\frac{r^2}{M^2a^2}\right) \text{ - field emission}$$

where $d = \dfrac{9.76 \times 10^{-9}F}{\phi^{1/2}\ t(y)}$ in eV and $t(y)$ is an image correction term

$$J = 6.2 \times 10^{-6}\,\frac{(\mu/\phi)^{1/2}}{\mu + \phi}\,F^2\exp\left(-6.8 \times 10^7\,\frac{\phi^{3/2}}{F}\right) \text{- field emission.}$$

II. THEORETICAL CONSIDERATIONS

A. Symbols Used in Text

α = semi angle (rad)

β = brightness (Acm^{-2} $sterad^{-1}$)

C_s = spherical aberration (cm)

D = diameter of central electrode (cm)

d = shield aperture diameter (cm)

d_o = beam diameter at cathode (cm)

f = focal length (cm)

h = filament height from shield (cm)

I_o = beam current at source (A)

I_i = beam current at image (A)

J_c = specific emission at cathode (Acm^{-2})

K = Boltzmann's constant (8.6×10^{-5} eV deg^{-1})

L = parameter (2S + T)

λ = electron wavelength (cm)

M = magnification

μ = Fermi potential (eV)

P = distance from source to plane of lens #1 (cm)

P_1 = distance separating lens #1 and lens #2 planes (cm)

ϕ = work function (eV)

ϕ_B = bias potential (V)

q = distance from anode to plane of lens #1 (cm)

q_1 = image distance from plane of lens #1 (cm)

q_2 = image distance from plane of lens #2 (cm)

R = gun efficiency

r = radial distance of lens aperture (cm)

S = spacing between electrodes (cm)

T = thickness of central electrode (cm)

T = absolute temperature (°K)

V_o = accelerating voltage (V)

V_L = center electrode voltage (V)

B. Electron Source

Although there are several electron source options presently available, as stated in the Introduction, the most widely used source for general electron-optical application is biased thermionically emitting tungsten filament[1]. This type of source in conjunction with the anode is frequently referred to as a triode gun configuration. The exit aperture in the grid cap, or Wehnelt shield as it is often called, can either be in a flat plate (flat shield) with the filament (cathode) positioned inside the shield, or it can be at the apex of a cone (reentrant) with the filament protruding through the aperture. Characteristic performances of the two types of shield configurations are given in Fig. 1. In the case of the reentrant shield the height dimension, h, is the distance the filament protrudes through the shield aperture.

For the present application we chose a reentrant design because it offers greater brightness at the specimen, since the cathode image position can be more readily controlled at the anode aperture plane, alignment and height adjustment are less critical, and a suitable unit is commercially available*. The brightness of a source is not to be confused with beam current. The important feature to remember about focussed beams is that it is only that portion of the emitted radiation that passes through the

*Filament assembly for Mini-Scan scanning electron microscope, distributed by Scan Atlanta, Atlanta, Ga. 30329.

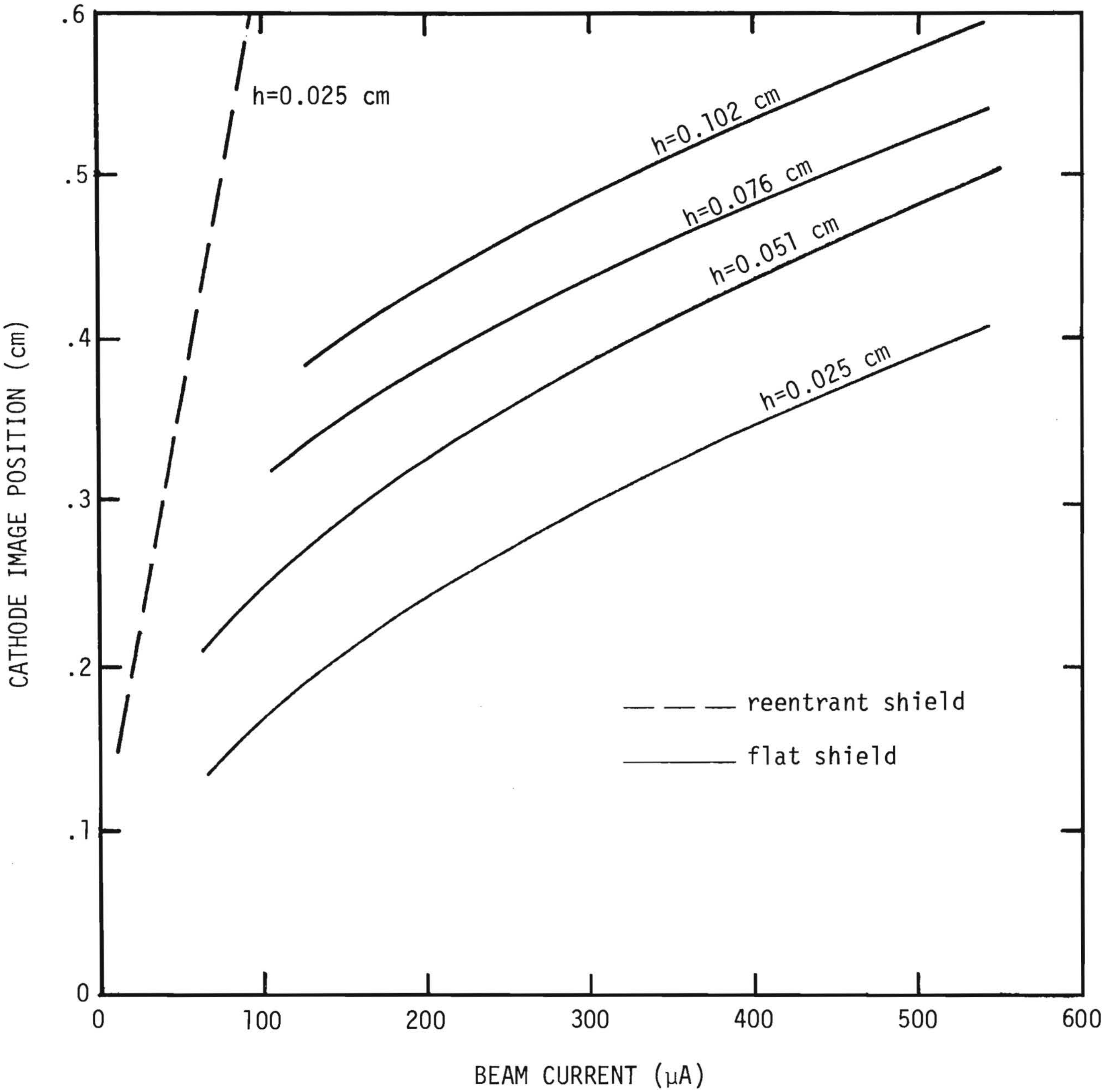


Fig. 1. Performance of several cathode gun designs, with cathode aperture of 0.12 cm diameter and high voltage at 50 keV- after Haine and Einstein, ref (1).

total aperturing system of the instrument and falls onto the object is useful. If the gun aperture is large, then only a small fraction of the emitted radiation will pass through the lens apertures. Such a gun is inefficient even though it may produce very large beam currents at the source.

Another factor to be considered in this particular application is the modulation of the beam at 4 MHz. In tetrode or pentode guns used in cathode-ray tubes, beam modulation is performed by changing the bias on the first grid (Whenelt shield). However, in cathode-ray tube guns the first grid is always of the flat shield type, placing the grid downstream from the emitter. In this situation the bias voltage can be driven to cutoff, thus enabling the electron beam to be intensity modulated from zero to maximum intensity.

With reentrant shields the beam intensity cannot be reduced to zero, which forced us to investigate another means of modulating the beam. The beam modulating topic will be discussed in another section of this report.

The total electron current density from a thermionically emitting tungsten filament is determined from Richardson's equation,

$$I_o = AT^2 \exp-(b/T). \tag{1}$$

The constants A and b are given by Hall[2] as 60.2 and 52,400 respectively. Calculated electron emission current densities as a function of filament temperature are given in Fig. 2. Also included in Fig. 2 is the relationship between filament lifetime and the operating temperature of the filament[3].

The normal operating temperature for a heated tungsten filament is

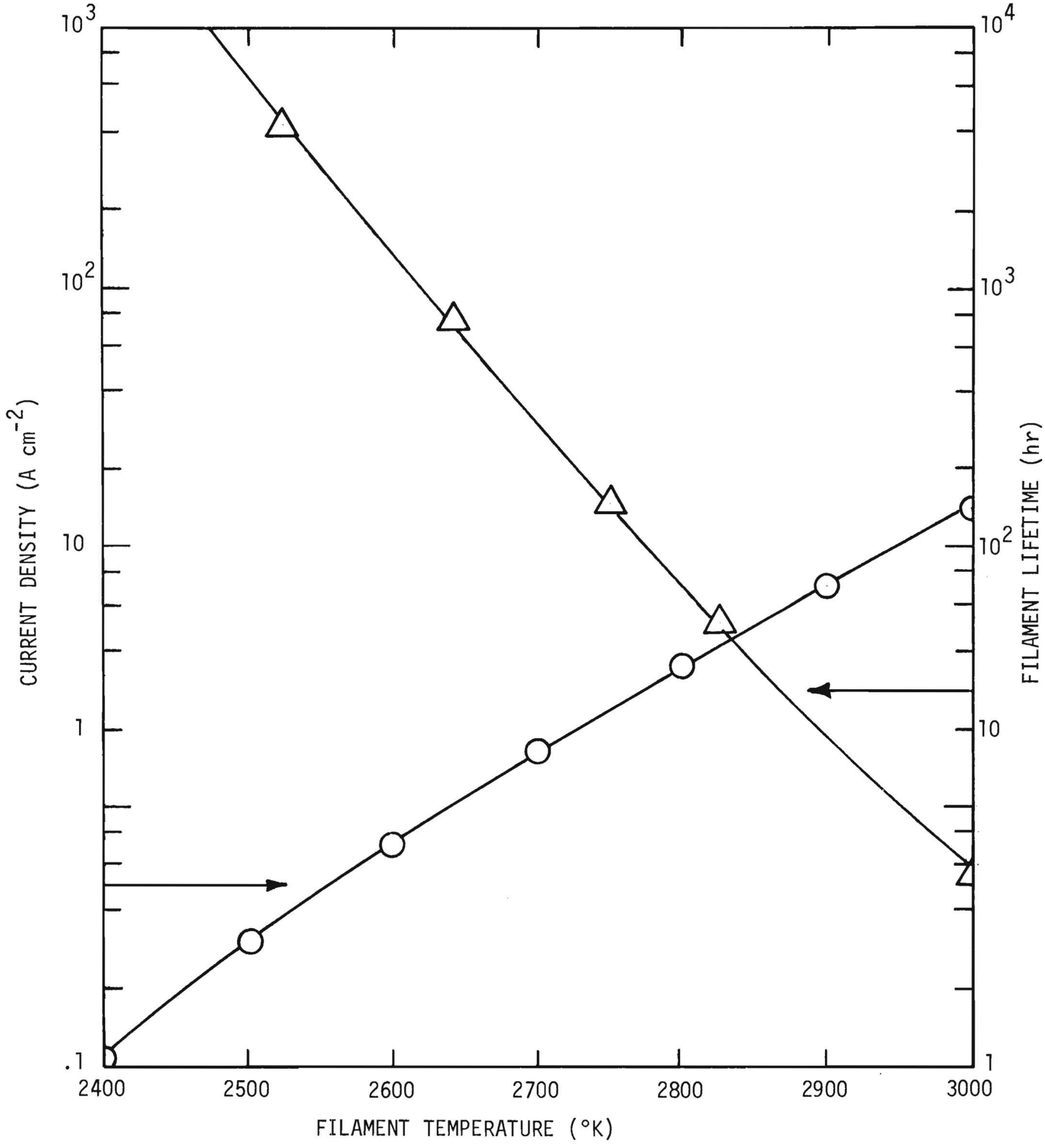


Fig. 2. Dependence of electron emission and filament lifetime on the operating temperature of a tungsten filament.

2700 °K, and under this condition the emission current density is about 1 to 2 Acm^{-2}. Current densities of about 30 Acm^{-2} have been recorded near the melting point of tungsten (3683°K), but as you can see from Fig. 2, the lifetime of the filament will be reduced to minutes.

Since this gun will be operating in ultrahigh vacuum, the filament lifetime will only be influenced by evaporation of tungsten from the filament and not by the added chemical activity of water vapor, which substantially reduces the service lifetime of tungsten filament during operation in high vacuum systems (10^{-5} to 10^{-6} torr). The lifetime data given in Fig. 2 were recorded in conventional high vacuum electron microscope systems and thus are somewhat lower than can be expected from the current gun.

C. Electrostatic Lenses

Since the geometrical restrictions of the IFLM dictated a probe forming lens with a working distance of about 25 cm a two lens system was considered necessary to produce an electron beam which would measure up to specification. Preference was given to electrostatic lenses over electromagnetic lenses for the following reasons: Electrostatic lenses are simpler to fabricate and can be made quite small and lightweight, and they are powered off the high voltage supply so they do not require additional supplies and this also reduces the chromatic aberration of the lens system. The usual disadvantages of using electrostatic lenses, namely a resolution limit of about 12 A and astigmatism due to contamination, do not apply in the present application; the reasons being that the gun will be operated at a conservative resolution of 25 microns and the system employs ultrahigh vacuum, which eliminates the otherwise severe contamination problems.

1. Considerations for Lens No. 1. Several requirements were set for

lens #1. These were as follows:

a) The central electrode should be operated at cathode potential in order to avoid the necessity of an additional high voltage feed-through.

b) The lens elements and spacings had to be as small as possible since this lens must have a small focal length. Also, the image must be outside of the potential field of the lens in order to reduce distortions.

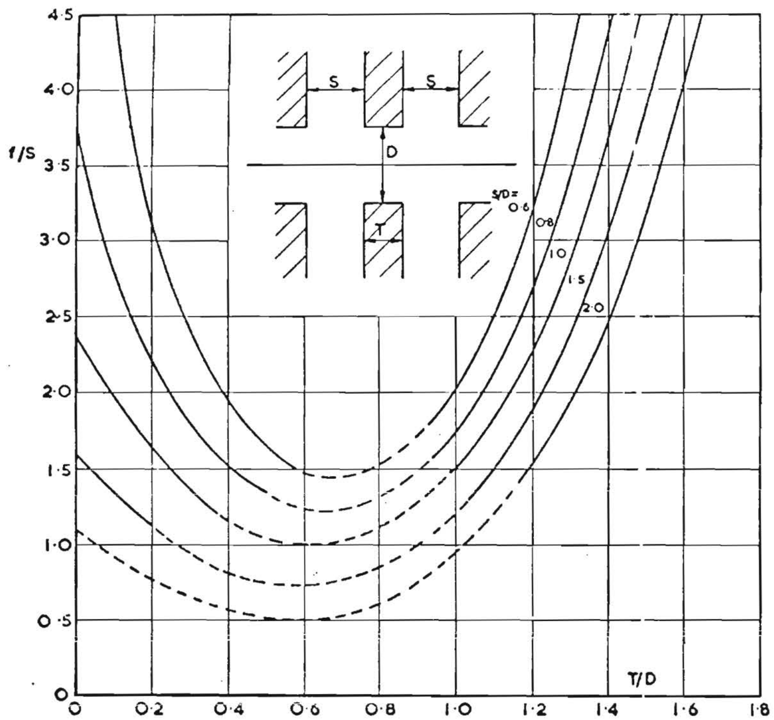
In order to arrive at suitable parameters both the lens data given by Grivet[4] and Haine[5] were investigated. It was found that these data gave essentially the same results, but since Haine's curves were a little easier to use, they were selected to make the final determination. Haine's curves are reproduced in Fig. 3.

After a number of combinations of S, T and D were considered, it was finally decided that the following lens geometry would be most suitable for the present application.

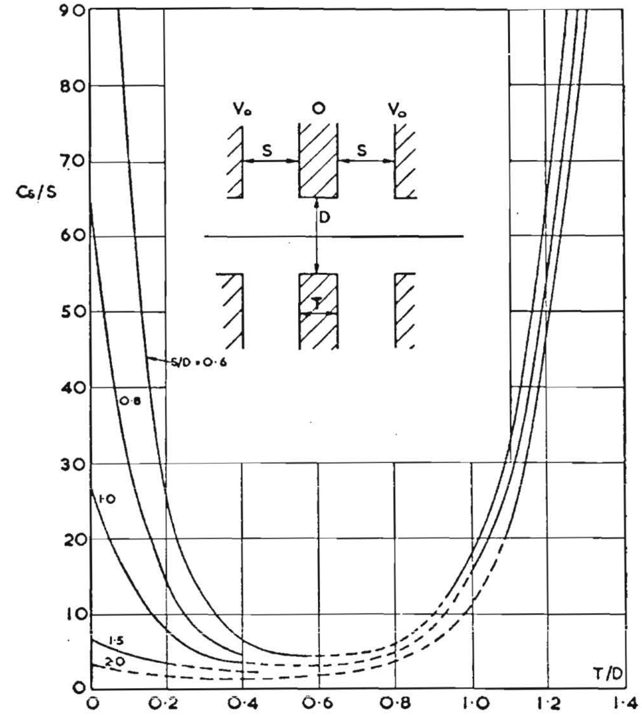
$q = 3.3$ cm, $q_1 = 0.6$ cm, $f = 0.48(0.5$ cm$)$, $C_s = 4.32$ cm, $S = 0.24$ cm, $T = 0.4$ cm and $D = 0.4$ cm.

2. Considerations for Lens No. 2

Since the purpose of this lens is to transfer the demagnified image of the source to the crystal, it can be treated as a weak transfer lens. Several requirements have to be met, however, which are to have as large an angular aperture as practical and for the center electrode to operate at as low a potential as possible. The large angular aperture allows maximum beam current to reach the target, while a low operating potential on the



Focal properties of the three electrode Einzel lens as a function of its geometry.



Spherical aberration of the three electrode Einzel lens.

Fig. 3. Focal properties and spherical aberration of three electrode einzel lenses with the center electrode operating at cathode voltage. Data taken from M. E. Haine, ref. (5).

center electrode will ease the design.

Various combinations of thick and thin center electrodes as well as large and small bore diameters were evaluated. The most suitable compromise for the various lens parameters was met with the following:

$q = 11.7$ cm, $q_1 = 26.0$ cm, $f = 8.07$ cm, $C_s = 2874$ cm, $S = 0.5$ cm, $T = 0.6$ cm and $D = 0.5$ cm.

The variation of focal length of lens #2 with electrode potential was calculated using the following expression

$$f = \frac{8}{3}\left(S + \frac{T}{2}\right)\left[\frac{1 + 2S/D - T/2D}{2SD}\right]^2 \Big/ \left(1 - V_L/V_0\right)^2, \tag{2}$$

where V_L is the center electrode voltage and V_0 the accelerating voltage. The results of these calculations are given in Fig. 4.

Location of the various components along the electron pathlength are given in Fig. 5. As a check on the previous calculations, the final beam size can be determined for the parameters given in Fig. 5 by the following expression,

$$d_2 = \frac{q_2}{\left(\frac{P_1}{q_1} - 1\right)P} d_o. \tag{3}$$

By substitution, d_2 is calculated to be 2.02×10^{-3} cm (0.0008 in).

D. Beam Intensity at Target

As the optical quality of the entire system is largely dependent on lens #1, a calculation was made to determine the angular aperture of this lens which would give optimum resolution with optimum intensity; the optimum value for this aperture was found to be 0.05 cm.

For the first approach to the problem, an aperture size of 0.076 cm was

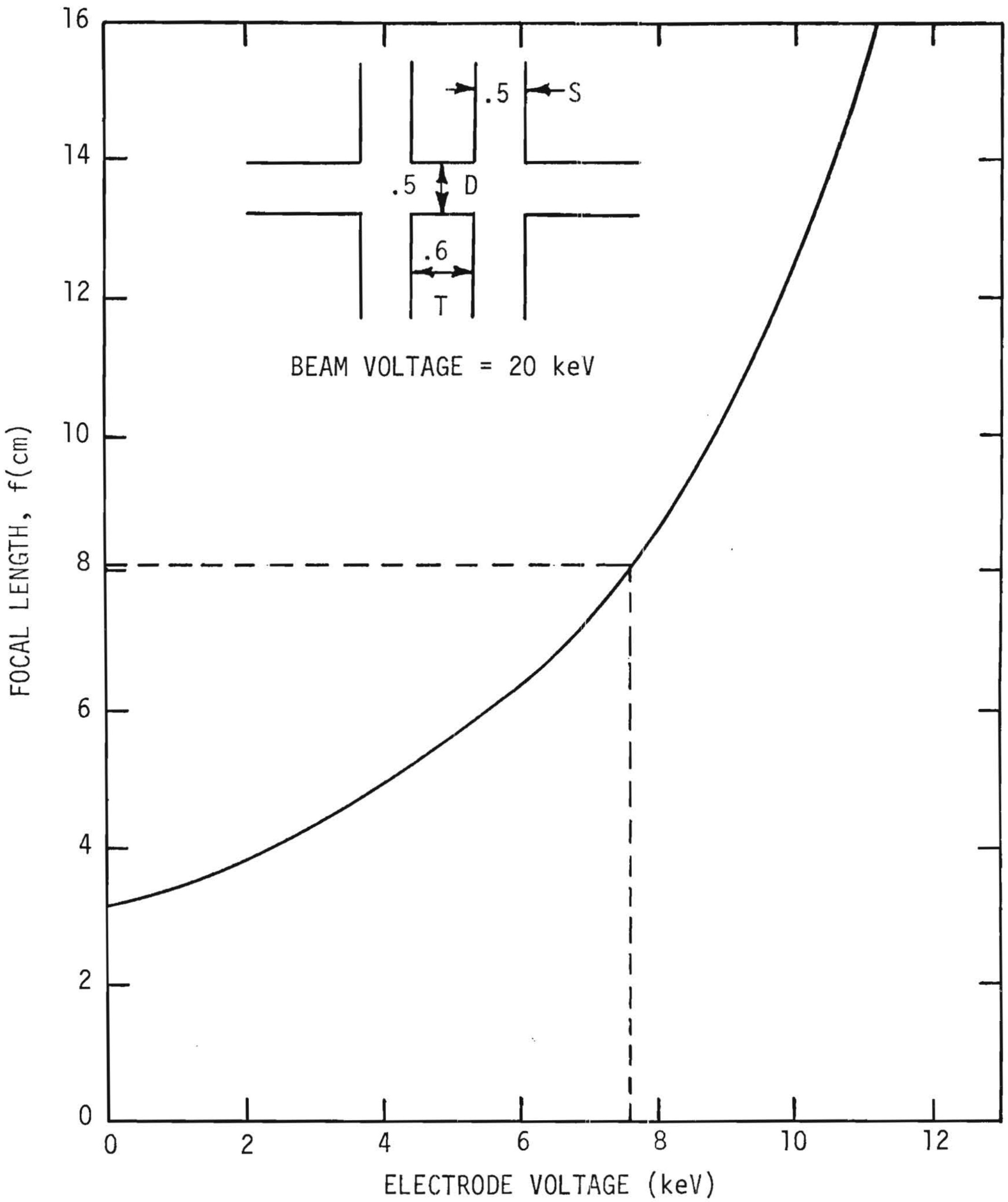


Fig. 4. Variation of focal length of einzel lens, having the parameters shown in inset, with center electrode voltage. Values calculated using formula (2).

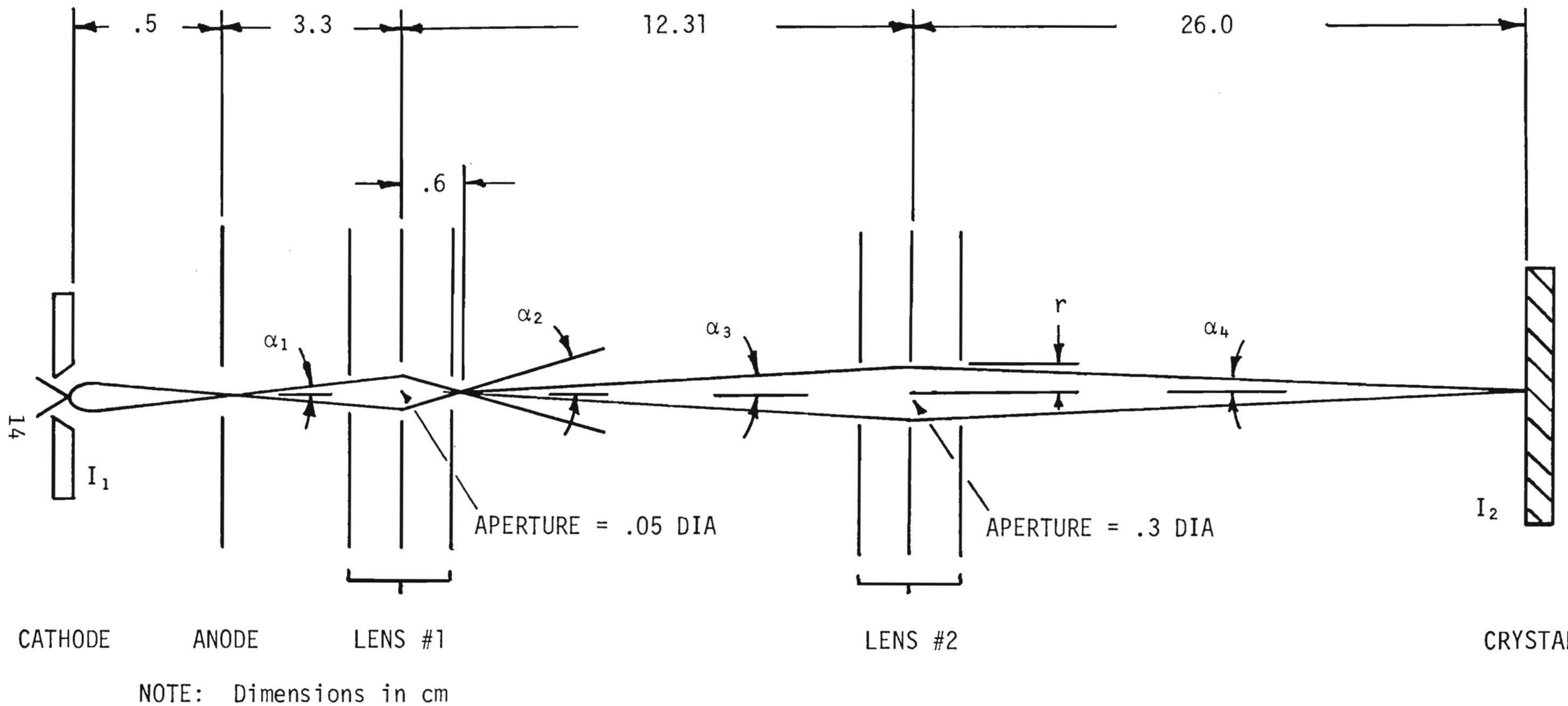


Fig. 5. Diagram showing the location of the major components along the electron pathlength.

selected, since this size aperture is commonly used in the condenser lens systems of commercial electron microscopes.

With the aid of the following equation[6]

$$I_i / I_o = (rM_1)^2/(P_1\alpha_1)^2, \tag{4}$$

values for beam current as a function of aperture size in lens #2 were calculated, and the results are given in Fig. 6. The results for a similar calculation using a 0.05 cm lens #1 aperture are also given.

If we now keep the aperture in lens #2 fixed and repeat the calculations for various aperture sizes in lens #1, the plot shown in Fig. 7 is obtained. Results using several values for lens #2 aperture are given in this figure. From these data it can readily be seen that a beam current of approximately 3×10^{-6} amp can be obtained in a 2.5×10^{-3} cm diameter beam (allowing for spread due to diffraction effects and lens aberrations) with apertures of 0.05 cm and 0.3 cm dia in lens #1 and #2 respectively.

All the beam current calculations were made on the assumption that the beam current at the cathode is 100 μA, a current value that one can expect from a reentrant type electron gun operating with the filament temperature between 2600 and 2700 °K.

E. Beam Modulation

In the original design, the Superior type SE-5Z write gun was modulated at 4 MHz by applying the output voltage from a video amplifier to the cathode biasing grid (G_1). The voltage required to drive this grid to cutoff was +75 volts. Since G_1 is essentially at the same potential as the cathode, i.e., -20 kV, the whole of the video amplifier and its accompanying power supply must have 20 kV isolation to ground. Also, to keep the time constant of the circuit suitably low for 4 MHz operation, all inter-

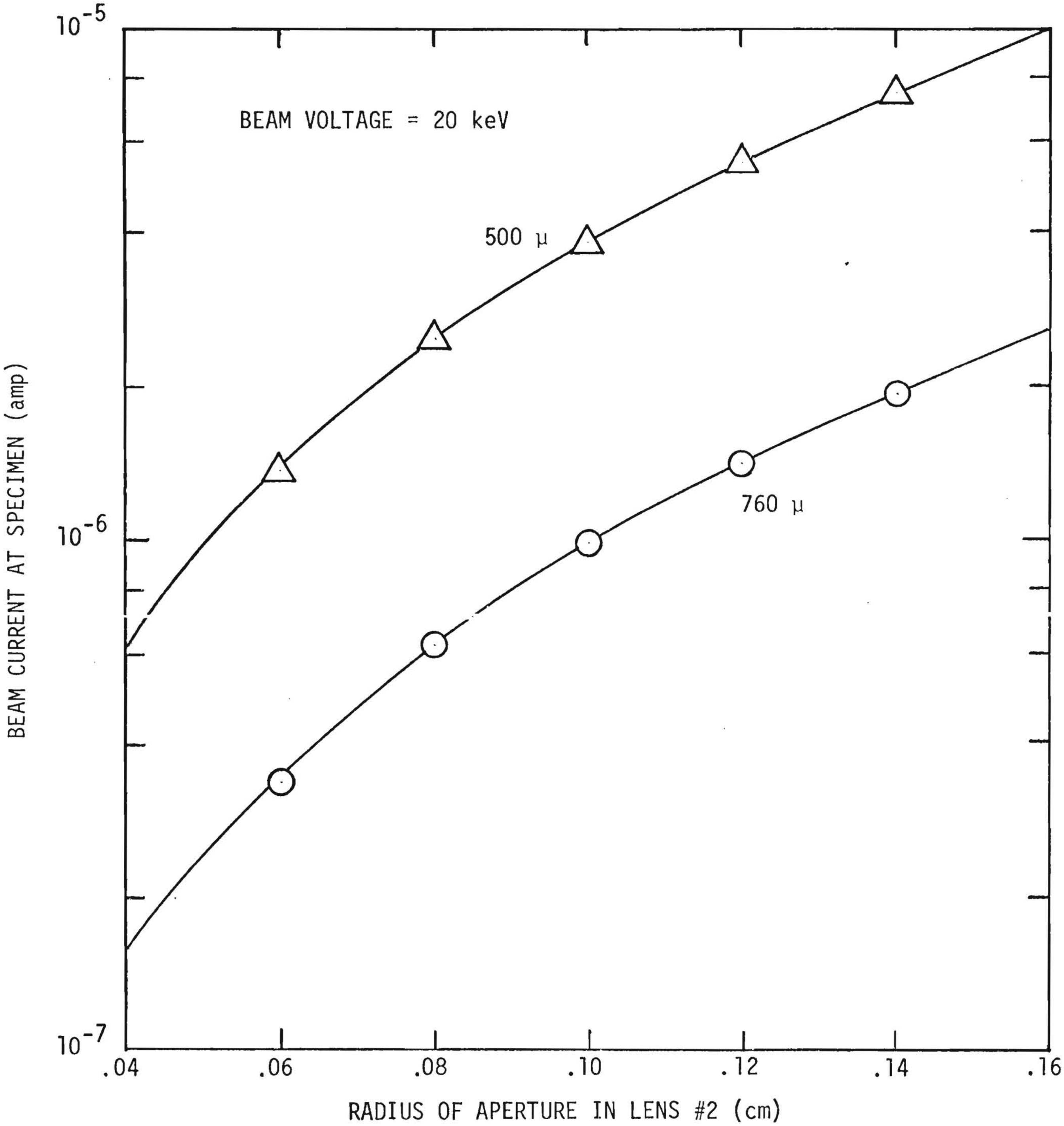


Fig. 6. Variation of probe current at the specimen with radius, r, of lens #2, for two sizes of lens #1 aperture, i.e., 500 μ and 760 μ.

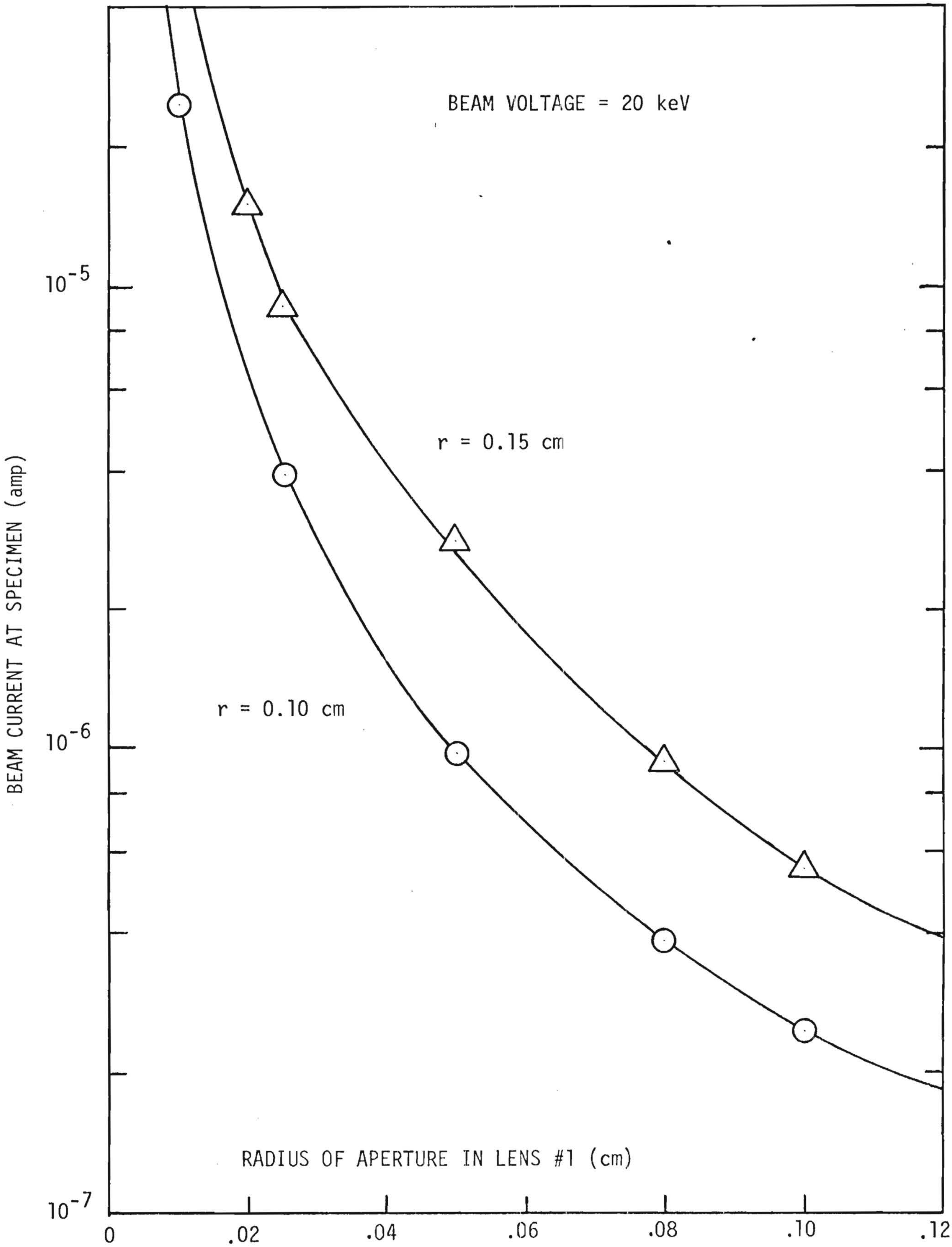


Fig. 7. Variation of probe current at the specimen with radius of lens #1 aperture, for two values of the aperture radius in lens #2.

circuit capacitances, as well as those to ground must be kept as small as practical.

During IFLM operation, a number of difficulties have been experienced with this beam modulating system. After deciding on a reentrant Wehnelt shield for biasing the cathode in the new electron gun, it was realized that beam modulation could no longer be accomplished in this way.

Several solutions to this problem were open to us with the present electron gun. One was to revert to a flat Wehnelt shield and build a new video amplifier with a 200 volt output and 20 kV isolation to ground or to continue to use a reentrant shield and use some other method of beam modulation. After discussions with J. R. Walsh, Jr., Electronics Division/EES, who designed the original video amplifier under Contract NAS8-27375, it was decided to modulate the beam intensity by sweeping the beam across an aperture, located on the cathode side of lens #2, by means of an electrostatic deflecting system. By going this route, the video amplifier operates at ground potential rather than floating at -20 kV, and the capacitance to ground can be kept below 20 pF.

However, the beam deflection method is not without its problems. The only convenient location for the deflection plates in the present gun is between lenses #1 and #2. In this space the beam is diverging from the image plane of lens #1 to the defining aperture size of lens #2, i.e., 0.218 cm diameter. It would be preferable to work with a converging beam, since under this condition the blanking aperture, over which the beam is swept, can be kept to a minimum. This situation, in turn, results in a low amplifier drive level.

With the diverging beam in the space between the two lenses, calculations were made using the equation[7]

$$V_{deflection} = 2ADE_o/L\ell^* \tag{5}$$

to determine the voltage required to deflect this beam out of the 0.218 cm aperture hole. Using 4 cm long deflection plates separated by 0.6 cm, ±180 volts is required to deflect the 20 kV beam outside the blanking aperture. In that part of the cycle in which the beam is passing through the blanking aperture hole, it will be focussed on the target and deflected by the raster generating deflection coils as if it was a direct current beam.

In the final modulator design, four plates were included rather than two, so that beam alignment with respect to the modulator axis can be effected by applying d.c. voltages to these plates.

---

* A = plate separation
D = deflection distance from axis
L = distance from center of plates to image plane
ℓ = length of deflecting plates
E_o = beam voltage

III. MECHANICAL CONSTRUCTION

A. Optical Column

The overall design concept of the electron optical column is shown in Fig. 8a. All the in-vacuum elements of this column are either attached to the six inch Conflat vacuum flange, A, or to the lens tube, C, which is bolted directly to the inside of flange A. All the necessary electrical feedthroughs, except the four pin feedthrough to carry power to the modulator, are located on flange A. These include the three connector pin high voltage bushing (two filament leads and Wehnelt shield bias), high voltage feedthrough for lead to lens #2, N in Fig. 8b, and three low voltage feedthroughs, O in Fig. 8b, for the stigmator drive voltages.

In this particular design, Lens #2 has been made the pivot point for the entire column, i.e., it has a fixed position with respect to the optical axis of the column and distance to crystal. In making lens #2 the pivot point, the other optical components in this column, i.e., the lens #1 and the cathode assembly, have built-in lateral adjustments so that they can be individually aligned to the optical axis of lens #2. The alignment of lens #1 is carried out on an optical bench and then locked in position with four retaining screws, F. The cathode assembly is externally adjustable by means of the gun alignment controls, T, shown in Fig. 8b. These controls allow a lateral adjustment of ± 0.15 cm about the optical axis and are essential during operation of the gun to compensate for thermal drifting of the cathode.

The beam modulator, I, together with the beam limiting aperture, J, for lens #2 are bolted to the top of lens #2 housing.

Several views of the finished electron gun and optical components are

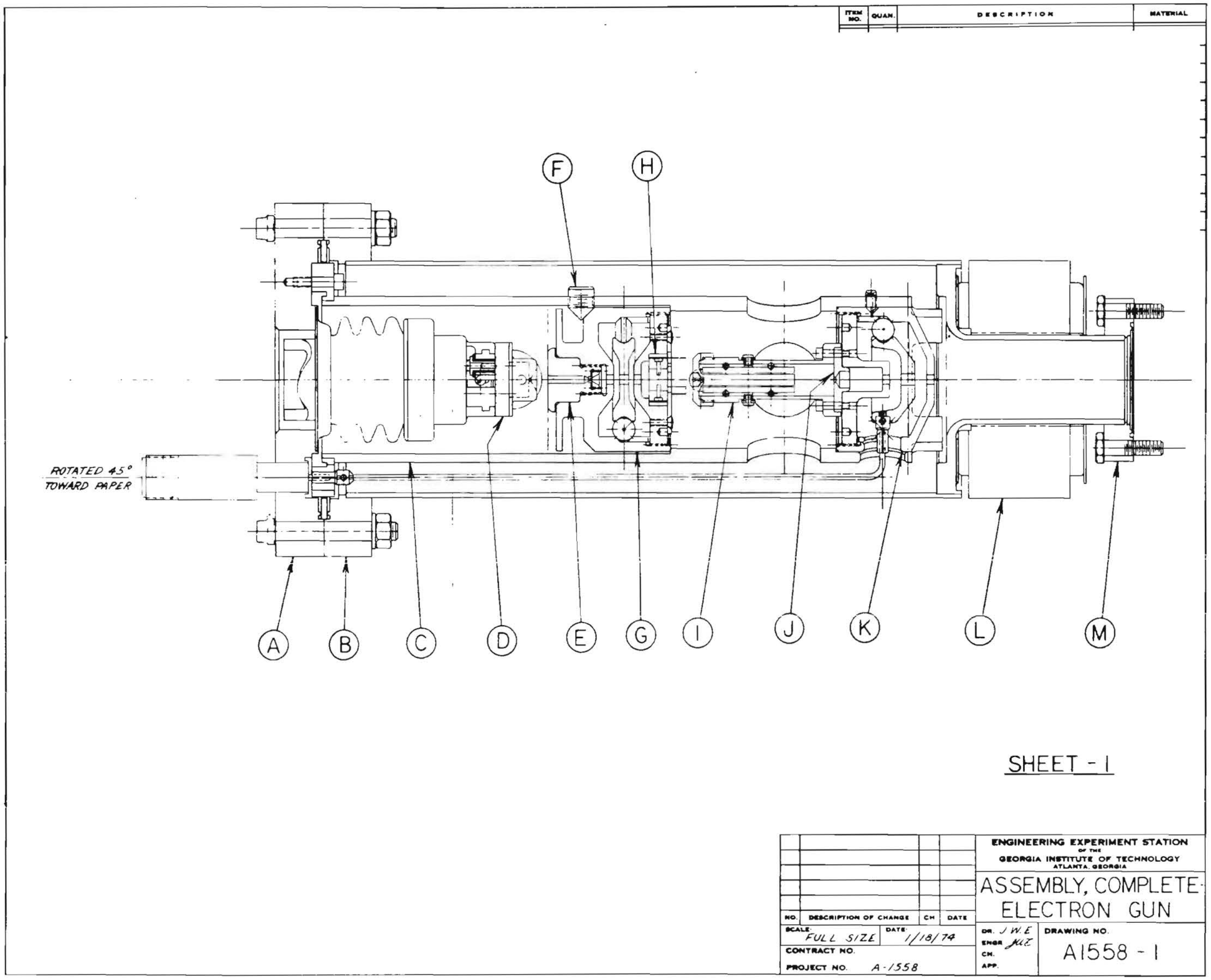


Fig. 8a. General assembly diagram of the complete electron gun.

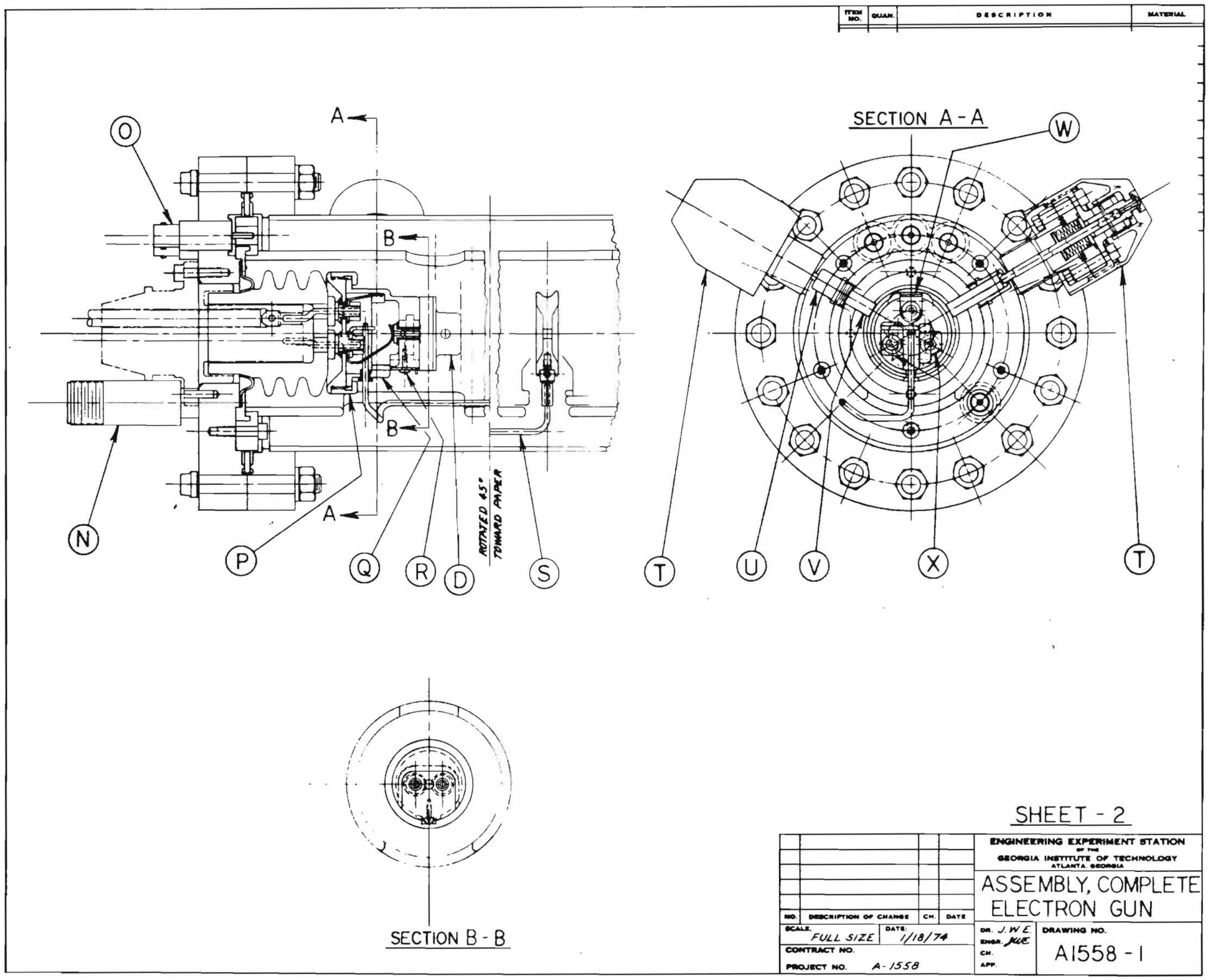


Fig. 8b. Assembly diagrams of the cathode showing details of the external centering mechanism.

shown in Figs. 9 and 10. Figure 9 shows the complete electron optical column removed from the vacuum housing. Figure 10 shows the vacuum housing, lens tube and the component sections of the two lenses.

1. Cathode Assembly. The cathode assembly was designed around a commercially available filament/Wehnelt shield assembly, D, (see Figs. 8a and b) in such a way as to not require any alteration to the purchased assembly. In order to do this, an interfacing sliding block, R, had to be used. Electrical contact to the filament is made via two sockets which are insulated from the block with boron nitride sleeves. An Allen screw holds the assemblies R and D together. A dovetail slide and retaining lug hold the assembly RD in the housing, Q. This housing in turn is attached to the base plate on the high voltage bushing by the screw-on collar, P. The collar, P, does not tighten onto the housing, and thus the housing is free to slide about in a groove to a lateral extent of $\pm$ .15 cm. Positive location of the sliding surfaces on the housing and collar is maintained by the two beryllium copper spring contacts, W, which also serve as electrical conductors to the filament.

Lateral positioning of the cathode assembly is accomplished by the linear motion controls, T, pushing the cathode assembly against the return spring, W. High voltage (-20 keV) insulation in the linear motion drives is obtained by using one inch long sapphire push rods, V, in the linear motion train. The sapphire rods are retained during removal of the optical column from the vacuum housing by the beryllium copper cups, U.

The filament circuit is insulated from the housing which is at the Wehnelt shield potential by mica and boron nitride washers. The high-voltage lead, S, to power lens #1 is attached to one of the filament con-

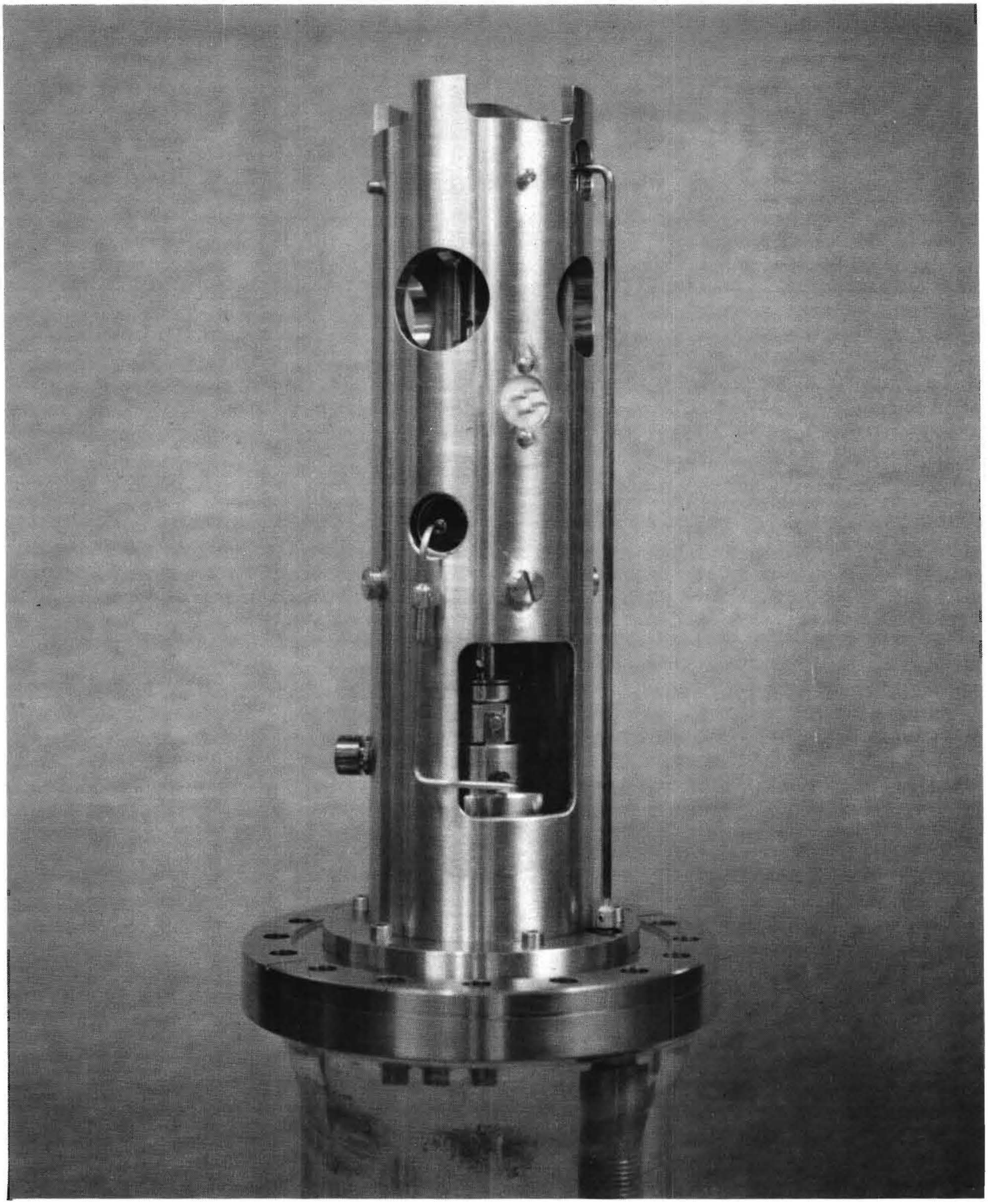


Fig. 9. View of electron optical column with the vacuum housing removed.

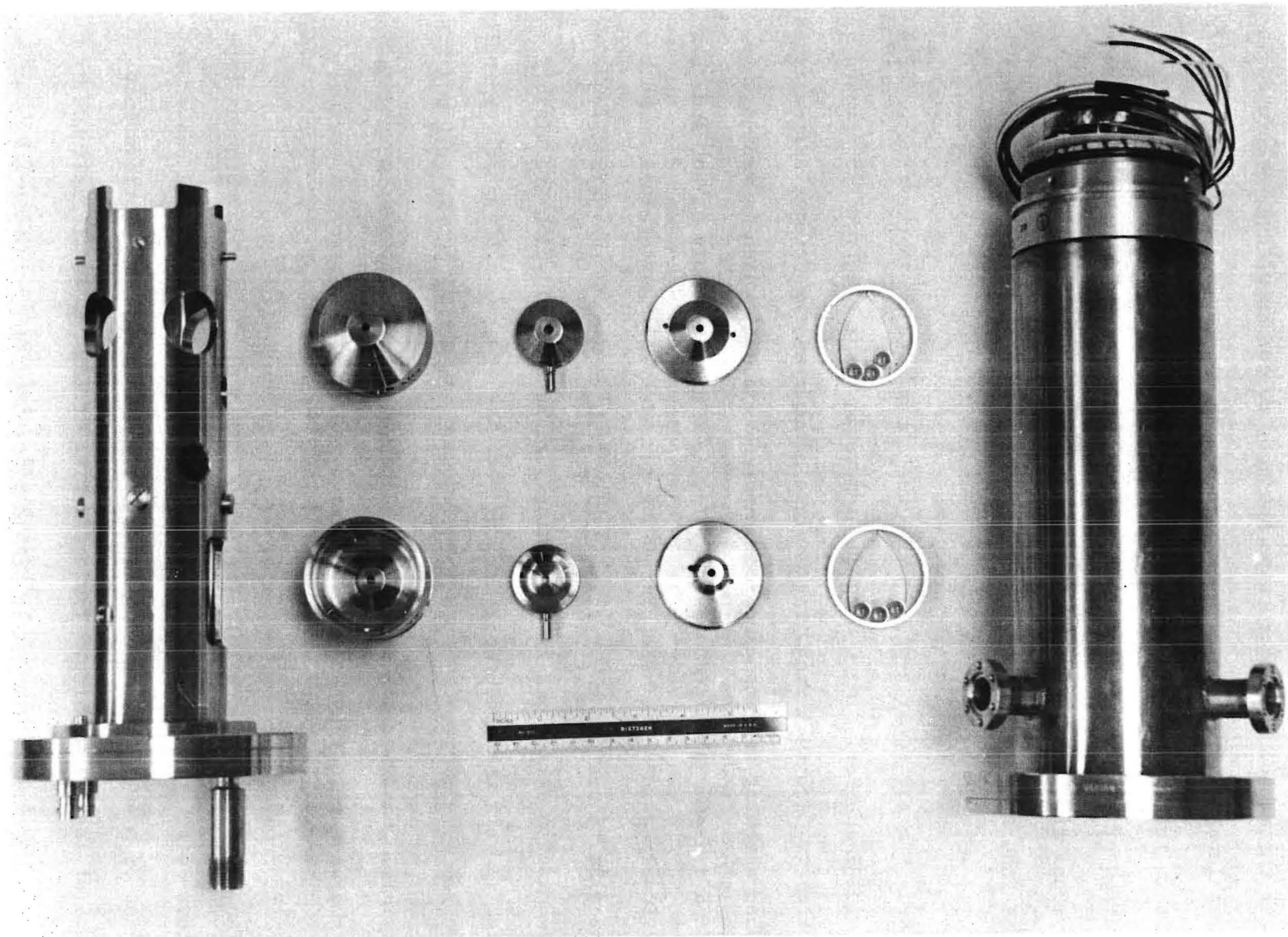


Fig. 10. Exploded view of lens tube, lenses and vacuum housing.

ductors and passes through an insulator in housing, Q.

2. Electrostatic Lenses. The design of lenses #1 and #2 are unique insofar as the method of construction has not, to our knowledge, been used in electron lens construction. In principle, the electrode assembly is closely similar to that of ball-race, as various views show in Figs. 11 and 12. Insulation of the 20 keV center electrode from the grounded outer electrodes is by means of three sapphire spheres, each 3/8 inch in diameter. These spheres locate in both inner (center electrode) and outer (outer housing) grooves. The outer groove is made up of two sections, one being a ridge machined into the housing wall, while the other section is the tapered edge of a stainless steel ring. When the removable outer electrode is screwed down tightly onto this ring, the whole electrode system becomes self-aligned.

When screwing the top electrode on or off, a jig, which is made from a 5/8 inch diameter plastic rod with a 1/4 inch diameter hole at one end, has to be inserted into the hole containing the high voltage terminal in such a manner as to prevent the retaining ring from turning with the electrode.

Two teflon strips and two retaining screws, both of which are visible in Fig. 12, are used to keep the three sapphire spheres 120° apart. Normally, these spheres are held securely enough that any movement in the cage would be impossible. However, the extra precaution was taken to prevent movement of the spheres should they become loose as a result of differential thermal expansion during bakeout.

The beam defining aperture for lens #1 is a platinum alloy Siemens type aperture* with a 400 micron hole size. This aperture is held in the anode by means of a retaining nut and the anode assembly, in turn, screws into the top of lens #1 housing. The aperturing of lens #2 is accomplished by a 0.218 cm hole in a stainless steel plate. This plate, together with the

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*Obtainable from Ernest F. Fullam, Inc., P. O. Box 444, Schenectady, New York, 12301.

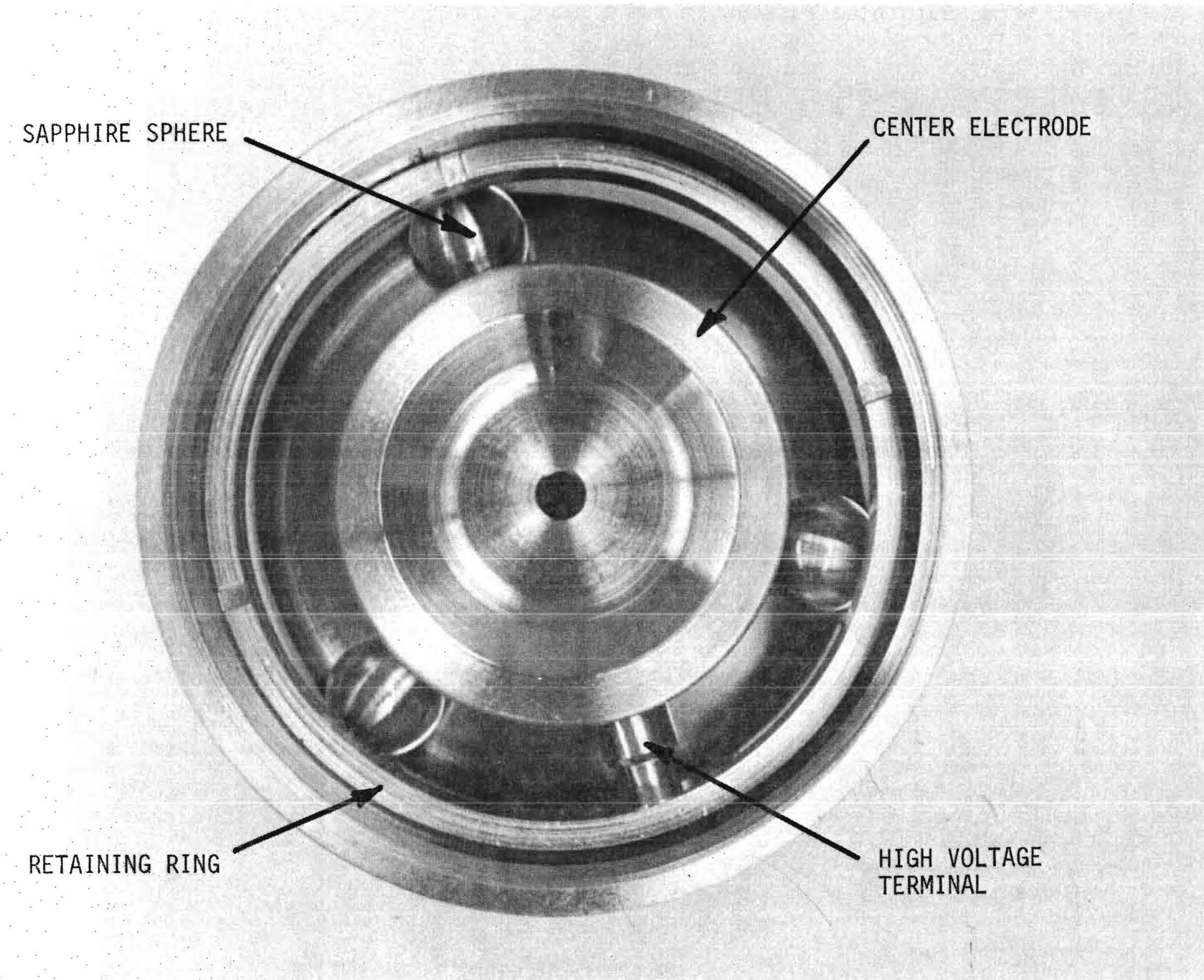

Fig. 11. Plan view of lens No. 1 with screw-on electrode removed. This view shows method of insulating center electrode from lens housing.

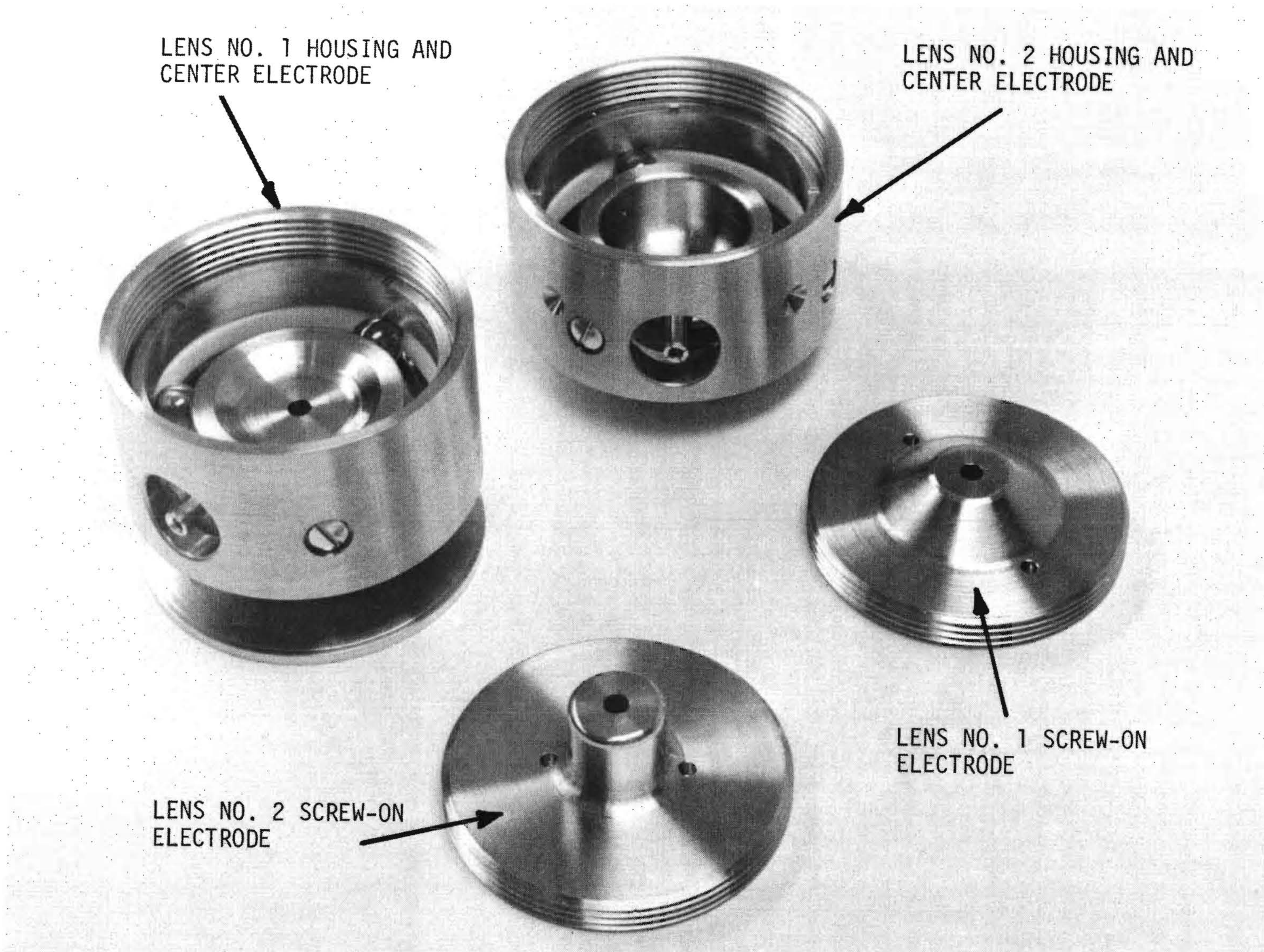

Fig. 12. Oblique view of lenses Nos. 1 and 2, showing retaining ball, retaining strips and screws.

beam modulator assembly, bolt directly onto the top of lens #2 housing.

Since lens #1 is operated as a strong lens, i.e., short focal length, it is necessary to correct for astigmatism. To accomplish this we have included a hexapole electrostatic stigmator, which is located concentric to the beam axis at the exit side of lens #1 (H in Fig. 8a).

3. Beam Modulator. This item is a stainless steel tube which bolts onto the top lens #2 with the lens aperture. The tube contains four deflection plates, which are electrically insulated from ground by 0.089 inch diameter sapphire rods. The capacitance of two plates plus the short electrical leads to outside the vacuum and the feedthroughs is slightly less than 20 pF. Where the beam enters the modulator a 750 Siemens type aperture is located. This aperture controls the size of the beam so as to insure that a particular voltage, when applied to the deflection plates, will remove the electron beam completely out of the hole in lens #2 aperture.

B. Vacuum Housing

The vacuum housing, B in Fig. 8a, is terminated at one end with a 6 inch Conflat flange and at the other with a 2 3/4 inch Conflat flange. There are three side entry ports welded into this housing.

Two of these are located near the 6 inch flange and they are separated from each other by 120°C. These two ports accommodate the linear motion feedthroughs, T in Fig. 8b, for cathode alignment.

About halfway down the housing there is a demountable four conductor electrical feedthrough. This feedthrough is for supplying power to the beam modulator. The conductors are located in a diamond arrangement with the diagonals aligned vertically and horizontally. Either diagonal pair of conductors can be connected to the modulator drive voltages, while the other two conductors are used for d.c. steering of the beam, should this prove to be necessary.

1. Magnetic Shielding. In order to shield the electric beam from stray magnetic fields, which both distort the beam and make alignment difficult, a cylinder of 0.010 in thick Co-Netic AA Perfection magnetic shielding material* was placed around the outside of the vacuum housing. This shield extended from the six inch Conflat flange, B in Fig. 8a, to the 2 3/4 inch Conflat flange, M in Fig. 8a. The cylinder is split the length of the gun and is held in position by two screw clamps. It was necessary to make this shield removable because it would not otherwise be possible to reach the bolts which attach flange M to the IFLM.

A note of caution is in order at this point. This shielding material is fully hydrogen annealed and thus is very soft. It rapidly loses its magnetic shielding property if it is unduly work hardened.

C. Beam Deflection Coils

A set of four electromagnetic beam deflection coils** is located on the vacuum housing next to flange M in Fig. 8a. Since this flange is welded to the end of the vacuum housing, this coil assembly is a permanent fixture. The coil assembly can, however, be rotated on the housing so that the raster generated by these coils can be lined up with the target crystal in the IFLM. Following alignment, the coil assembly can be locked to the housing with a set screw.

The electrical connections to these coils are shown in Fig. 13. The

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* Magnetic Shield Division, Perfection Mica Company, 740 Thomas Drive, Bensenville, Illinois 60106.

** Constantine Engineering Laboratories Company, Mahwah, New Jersey, 07430, Part No. AY521-5612/540.

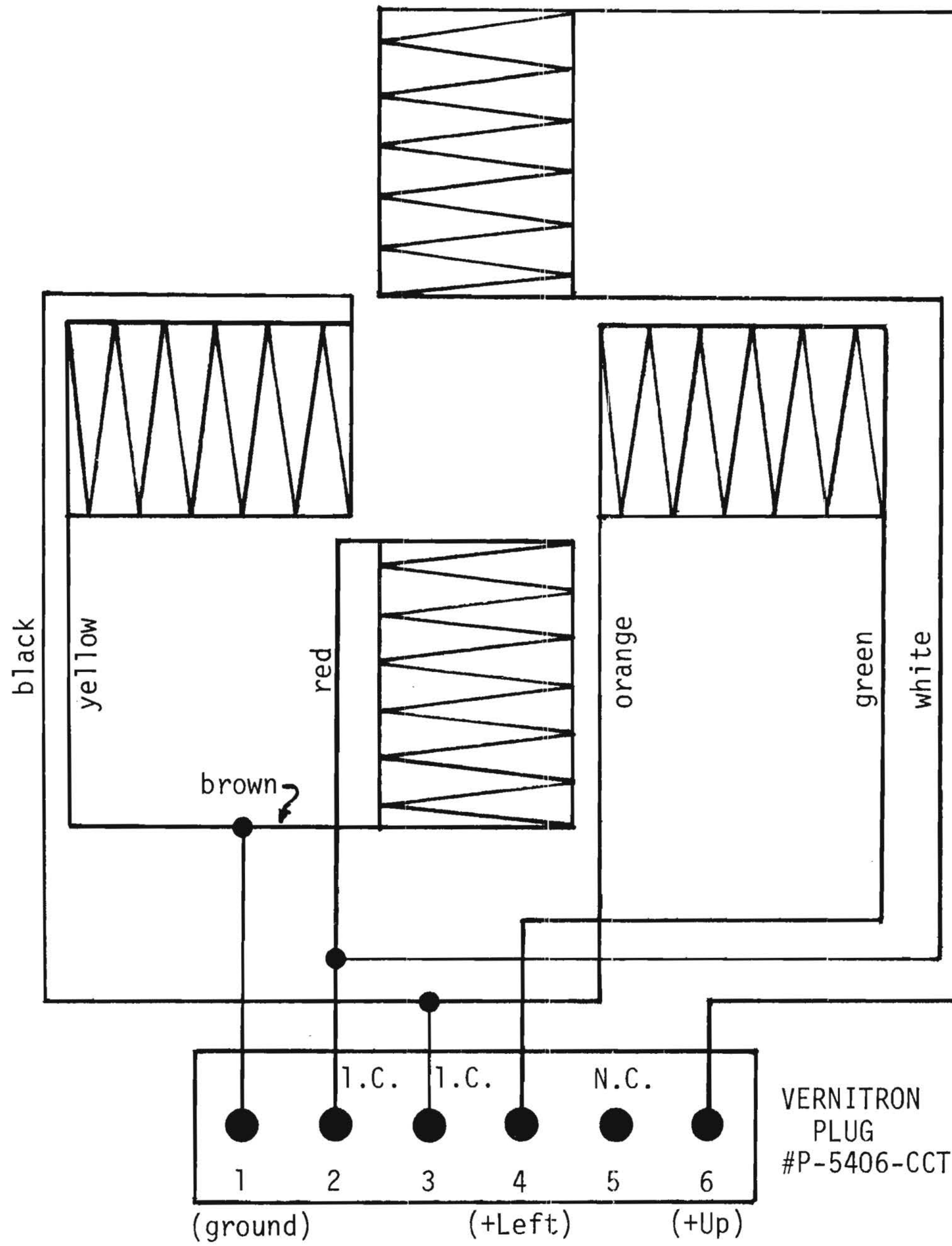

Fig. 13. Wiring diagram for beam deflection coils.

connector used to attach these coils to the IFLM electronics is a 6 pin Vernitron plug, type P-5406-CCT. A ground return is used and each pair of opposing coils is joined internally.

Should it ever be necessary to remove the electron gun from the IFLM, the deflection coil plug has to be removed so that the magnetic shielding can be withdrawn from the gun housing, and thus exposing the attachment bolts holding flange M to the IFLM.

D. Electron Gun Control Module

The electrical controls for operating the electron gun are housed in a 8 1/2 inch high relay rack unit, shown in Fig. 14, front panel view, Fig. 15, inside view looking from top and Fig. 16, plug layout at rear of cabinet. Housed in this cabinet are the necessary controls to operate the filament, focussing lens #2 and stigmator in lens #1.

All the high voltage cabling (RG8/U coaxial cable) plugs into this unit by means of special high voltage plugs (see Fig.A69) which were designed specially for this system. High voltage is supplied to the control unit by a Spellman 0-20 keV high voltage supply, Model No. UHR20N10. There is also a 115 Vac input power line for operating the filament power supply and the stigmator supply.

In the front panel view, Fig. 14, the convenient grouping of the various controls is shown. The electrical circuitry to which these controls relate is shown in Fig. 17, and a description of each of the components in this circuit diagram is given in Table II. Most of the controls are self-explanatory and their functions will not be further outlined at this time. The operation of the stigmator is probably not obvious to most readers and its operation will be explained in detail in the section on gun operation.

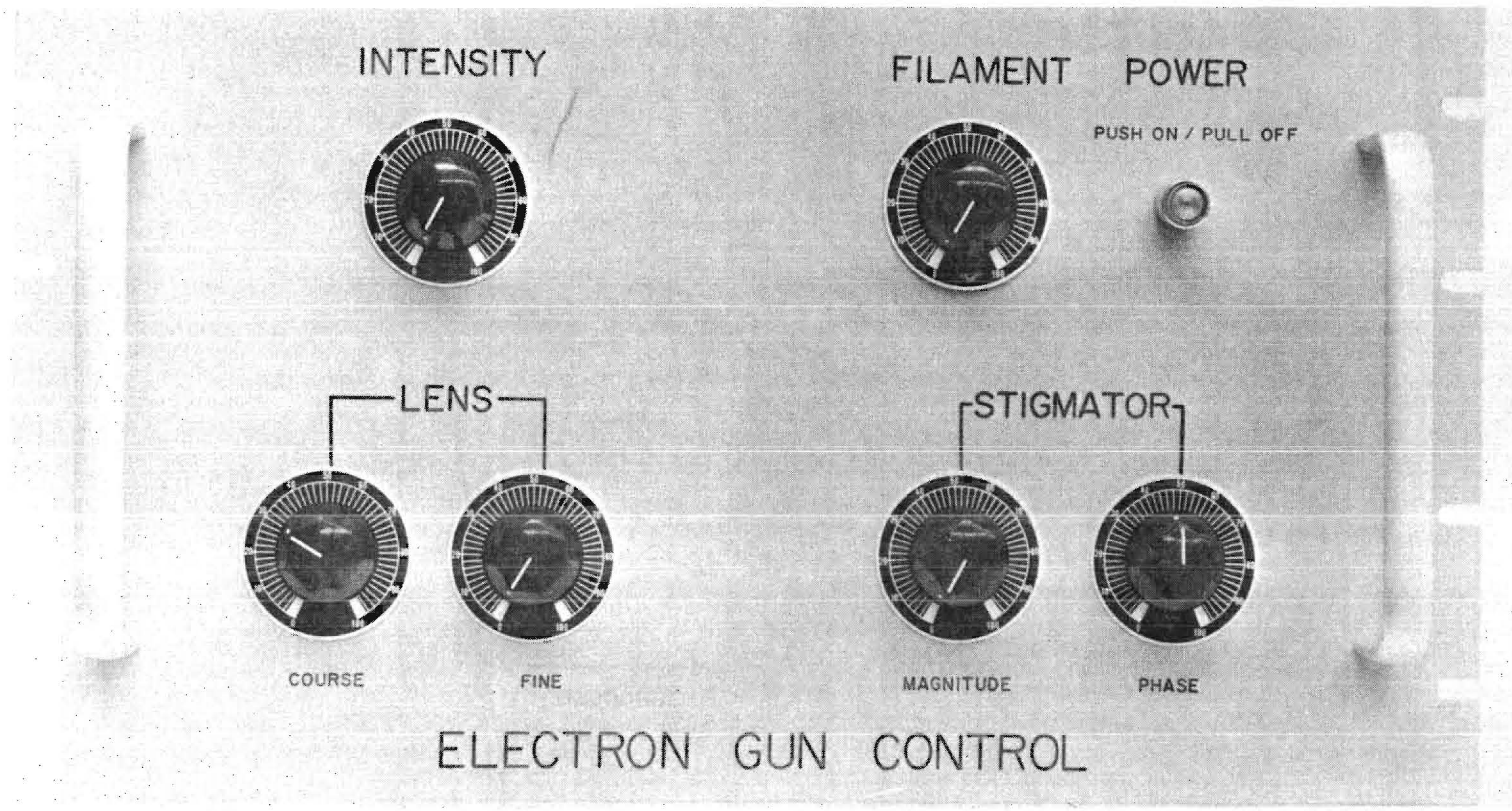

Fig. 14. Front panel view of gun control module.

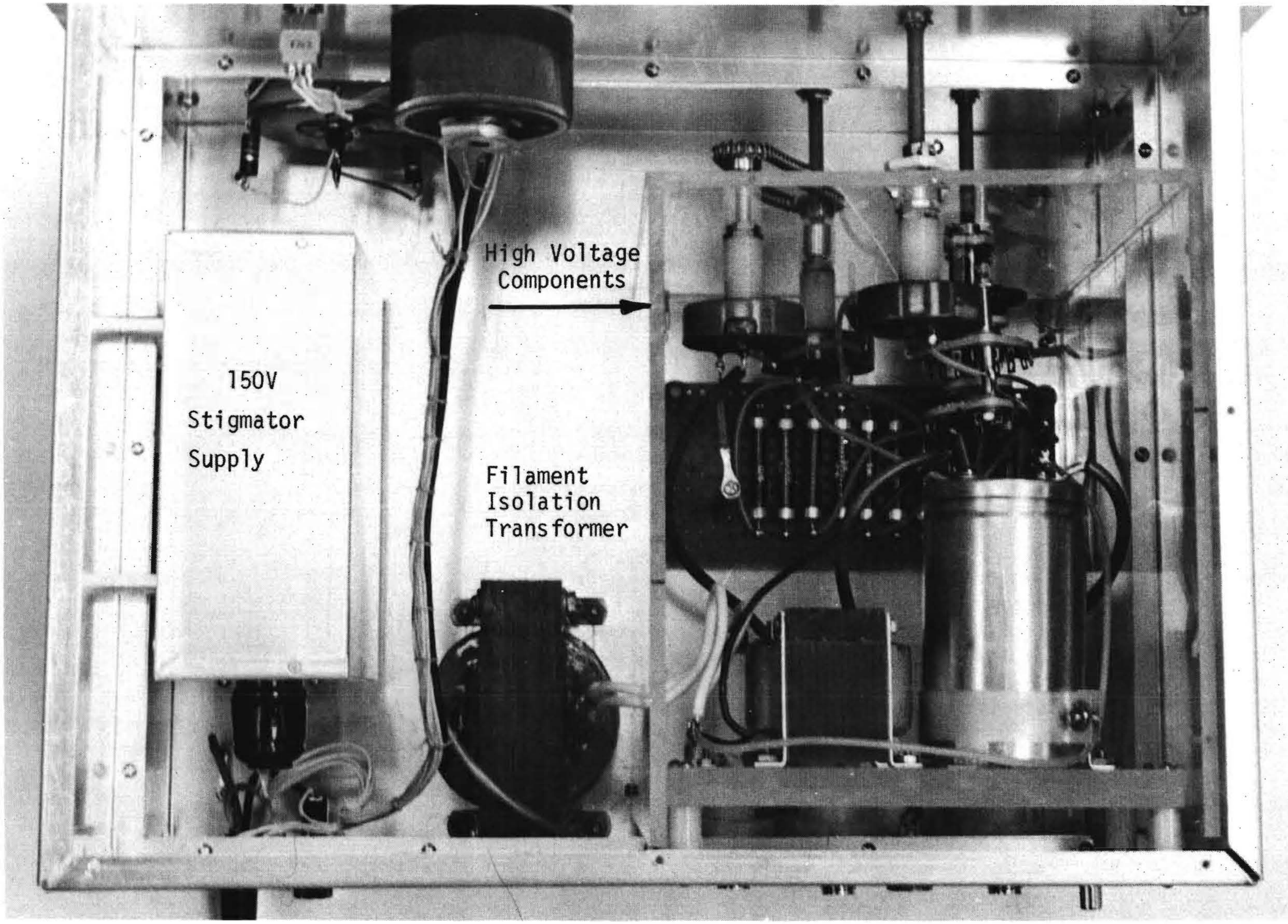

Fig. 15. Plan view of gun control module, showing layout of components.

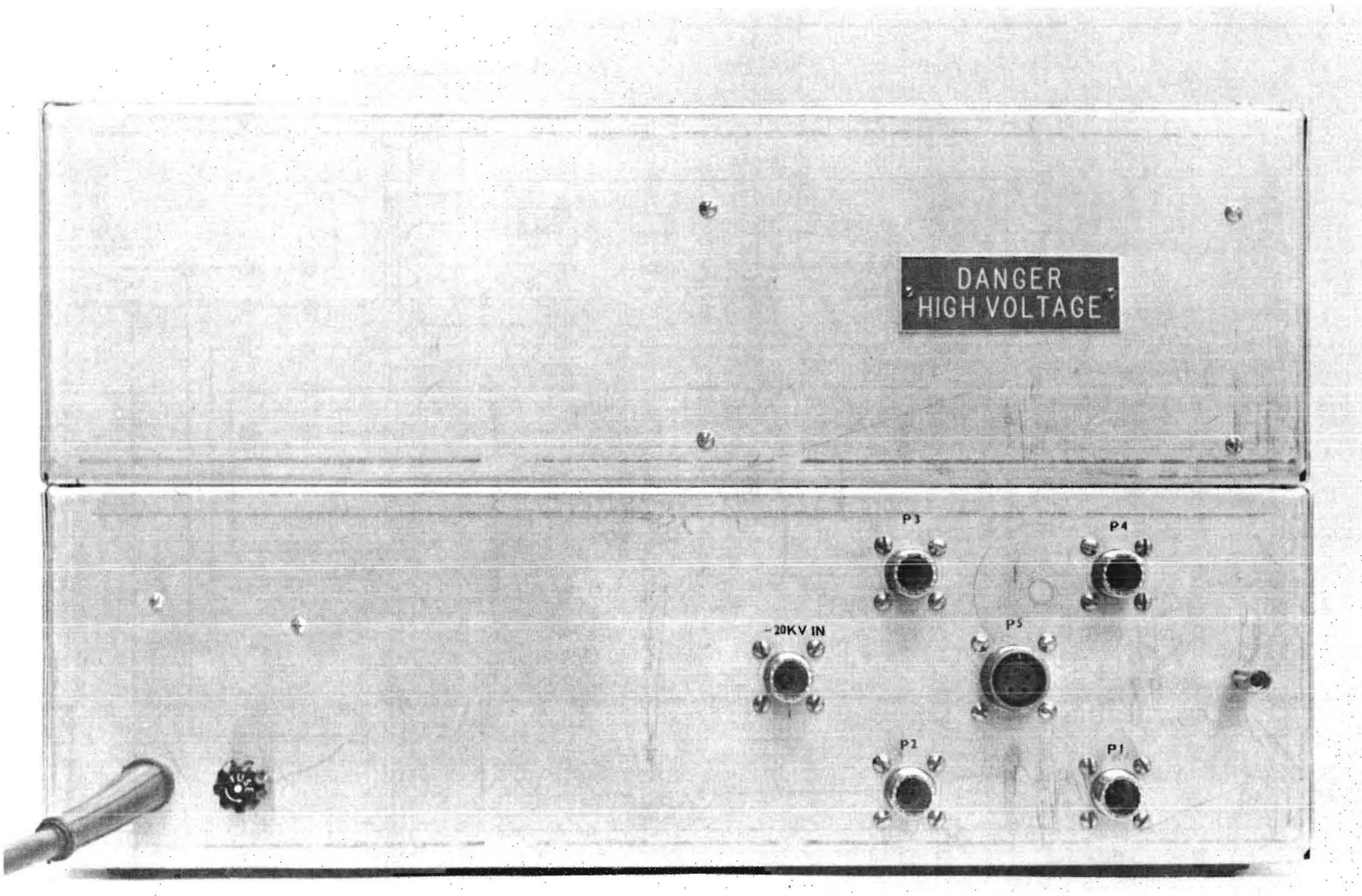

Fig. 16. Plug layout at rear of gun control module.

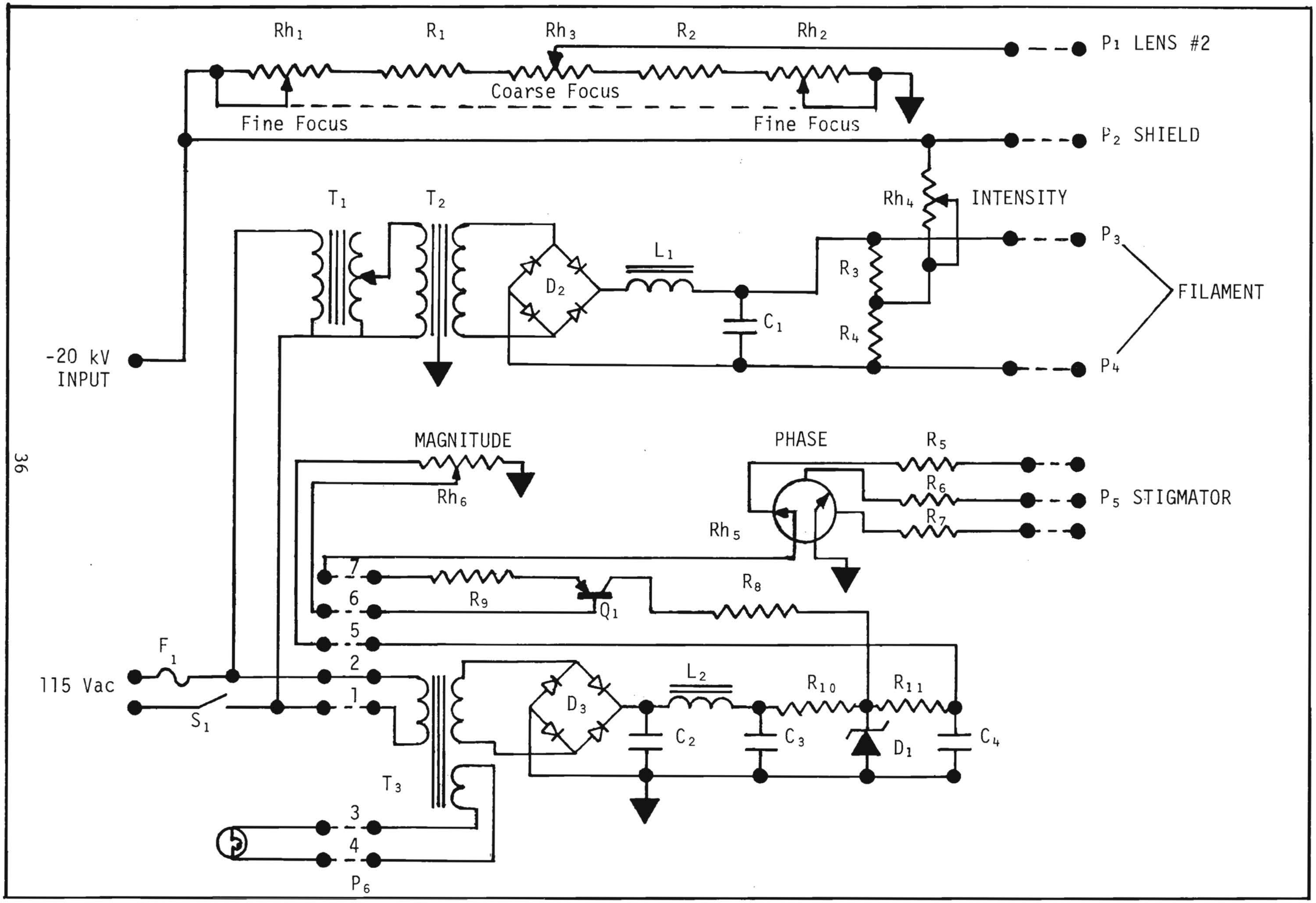

Fig. 17. Wiring diagram for circuits used in gun control unit.

Table II. List of components for electron gun control unit.

List of Components

C_1 15,000 μF 50 V (Sprague)

C_2 60 μF 250 V

C_3 60 μF 250 V

C_4 4 μF 150 V

D_1 IN5383 (Motorola)

D_2 MDA970-2 (Motorola)

D_3 MDA942-6 (Motorola)

F_1 1 amp fuse

L_1 6 X 29

L_2 C-1003 (Stancor)

P_1 Lens #2 high voltage plug

P_2 Shield high voltage plug

P_3, P_4 Filament plugs of high voltage

P_5 Stigmator (Amphenol 148-5S)

P_6 150 V supply (9-pin octal)

Q_1 MJE 340 (Motorola)

R_1 275 Meg (Victoreen HVC, 3 W)

R_2 150 Meg (Victoreen HVC, 3 W)

R_3 100 Ω/1 W

R_4 100 Ω/1 W

R_5 56 kΩ/1 W

R_6 56 kΩ/1 W

R_7 56 kΩ/1 W

R_8 27 kΩ/2 W

R_9 100 Ω/2W

R_{10} 8.2 kΩ/2 W

R_{11} 39 kΩ/1 W

Rh_1 25 Meg (Clarostat CM40533)

Rh_2 25 Meg (Clarostat CM40533)

Rh_3* 5 Meg x 10 (Victoreen MOX-2)

Rh_4 5 Meg (Clarostat CM40534)

Rh_5 55.5 kΩ sin/cos (Spectrol 400-831)

Rh_6 100 kΩ/2 W wire wound

S_1 Single pole ON/OFF Alcoswitch with type 328 indicator lamp (GE)

T_1 Variac (Staco, type 171)

T_2 Model T117/25-0.05 IA 20 kV insulation

T_3 PS8416 (Stancor)

*Ten 5 Megs in series with taps between each one to switch.

The top view of the control unit shown in Fig. 15 shows the layout of the various components inside the cabinet. All the high voltage components are grouped on the right-hand side of cabinet, when looking down from the rear of the cabinet. Additional insulation is afforded by placing all these components in a plastic box. The three control potentiometers and rotary switch selector for coarse lens control are actuated by means of 1/4 inch diameter fiber glass rods. These can be seen at the top right-hand corner of Fig. 15.

Primary a.c. power, which is rectified for heating the filament, is passed through an isolation transformer, which is seen at the lower left center of Fig. 15. A 150 V d.c. supply for the stigmator is housed in a separate aluminum box, shown at the left of Fig. 15.

The control unit is connected to the electron gun through 10 feet of cabling. The filament and shield supplies plug into the electron gun housing by means of a special, three conductor high voltage plug, (see Figs. A70 through A74). There is an aligning pin provided in the gun flange to insure the proper positioning of this plug in the gun housing. Another special high voltage feedthrough (Ceramaseal* No. 809B7546-1) is used to connect the focussing voltage lead to gun housing. The three stigmator leads are connected to Ceramaseal type 804B5230-1 feedthroughs by means of standard BNC plugs.

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*Ceramaseal, Inc., New Lebanon Center, New York 12126.

IV. OPERATING PROCEDURE

A. Column Alignment

The optical column is aligned with respect to lens No. 2, which is the reference point for the whole column alignment procedure.

In the final assembly of the electron gun system the mechanical alignment of lens No. 1 was effected by using a #53 drill (0.059 in) in the angular gap between the outer lens housing and the wall of the lens tube. Opposite pairs of the four support screws were gradually tightened until the drill shank could be moved all around the anulus. At this point the lens is aligned to better than 0.001 inch with respect to the mechanical axis of the lens tube. Should it ever be necessary to remove lens No. 1 from the lens tube it will require realignment in this manner during assembly of the optical column.

It will be necessary to align the cathode assembly at frequent intervals, both after each dismantling of the column from the vacuum housing, and during operation of the gun. The filament is in a coaxial position when the external cathode adjustment knobs are screwed in clockwise to between two and two and a quarter revolution from their outer stop position.

Once the filament alignment position has been located, it will be necessary to check for thermal drifts of the filament by monitoring the beam current. The filament alignment can be readily adjusted by observing the specimen current flowing from the target through an electrometer to ground. The mechanical adjustment controls are moved until the beam current is peaked at the specimen.

It is also possible to electrically trim for column out-of-alignment by means of the four electrostatic deflection plates in the beam modulator assembly. However, the use of these plates for correcting alignment should be kept to a minimum.

B. Operating Conditions

For normal operation of the electron gun it is assumed that the electron-optical column is aligned, as described in section A above, and the system has been evacuated to at least 10^{-5} torr.

The first operation is to turn the high voltage supply on and increase the voltage to 20 kV. Should any particulate matter be on the insulators at this time, they will most likely cause a sparkover, and such an event will trip the safety interlock in the Spellman supply. Should a sparkover occur, it will be necessary to turn the voltage increase knob to zero and then increase it again to 20 kV. Repeated flashovers will usually indicate a "dirty" system and this can only be rectified by a thorough cleaning of all components subjected to high voltage, as well as the interior of the vacuum system.

With the high voltage turned on, the filament supply can now be turned on, but only after making sure that the filament control knob is turned counterclockwise all the way to zero. The filament temperature is increased to the normal emission temperature of about 2700°K by turning up the filament control to dial setting #32. This setting will change with filament life, and from one filament to another. The best operating setting will have to be determined for each new filament by trial and error. However, the operator is cautioned not to greatly exceed the normal operating setting as the filament will be burnt out.

The optimum bias setting for this cathode assembly appears to be with the intensity dial at 81. Increasing the intensity control setting reduces the bias and the gun approaches an unbiased, or diode, configuration. Turning the intensity control anticlockwise increases the bias until cut-off occurs at about position 75 on the dial. As part of the shutdown procedure it is wise to return <u>all</u> control knobs to their zero position.

Finally, before the beam scanning and modulating systems are turned on, the column alignment should be optimized, using a fluorescent screen in place of the target crystal. The gun is now ready for operation and now the scanning and modulating system can be turned on and the target crystal lowered into position.

C. <u>Dismantling the System</u>

It is extremely important that the following dismantling procedure be strictly adhered to, otherwise costly damage may result.

Before the 6 inch Conflat flange, see A, in Fig. 8a, containing the lens tube and optical components can be removed from the vacuum housing, B, in Fig. 8a, three items have to be withdrawn from their normal position. These are the two linear adjustment controls, T in Fig. 8b, and the four-pin feedthrough on the side of the vacuum housing which carries voltage to the modulator.

Firstly, the four-pin feedthrough should be removed by undoing the six holding bolts and unplugging it from the inner plug, which is attached to the lens tube, with a gentle, straight pull. There is a scribe mark across the sides of both flanges so that the flange can be reassembled in the correct position.

Next, withdraw both linear motion feedthroughs by screwing them to their full counterclockwise positions. This operation requires about two turns of each knob. Do not force the knobs after they have reached the end of their travels, otherwise damage to the metal bellows may result.

Remove the two screws holding the high-voltage plug in position and then remove the high voltage plug. The lens control cable and stigmator leads are also removed at this time.

Remove the bolts holding the six inch Conflat flanges together and then gently withdraw the optical column from the vacuum housing. During this operation both the column and housing should be kept as near concentric to each other as possible. A suitably sized screw driver may have to be inserted into the diametrically opposed slots in the flanges to pry them apart. Likewise, the used copper gasket may have to be pried out of its seating. A screw driver can also be used for this purpose, but great care must be exercised in avoiding damage to the knife edge sealing surfaces on these flanges. A pair of wide nosed pliers gripping the copper gasket across the flat is usually a better and safer method of removing copper gaskets.

Replacing the optical column in the vacuum housing is the reverse of the dismantling process, with several additional points to be observed. For the optical column to be properly seated in the vacuum housing, it has to be positioned in the groove at the far end of the vacuum housing. After a new copper gasket has been placed in position the optical column is inserted into the vacuum housing and manipulated until it is properly seated and oriented. The scribe marks on the two six inch flanges should be aligned. The flanges are then bolted together.

Next, the connectors on the four-pin feedthrough are plugged into the pins which protrude from the connector in the lens tube. Care must be taken in positioning this feedthrough as locating the inner pins has to be done blind and excessive force will bend the pins out of alignment. Again, make sure that the scribe lines on the flanges match up.

The linear motion feedthroughs can now be screwed clockwise into position (2 to 2 and 1/2 turns). Finally, plug in the electrical connectors and secure them to their respective housings.

V. PERFORMANCE OF THE ELECTRON GUN

At the time of writing this report it was not possible to test this electron gun in the IFLM since a number of the circuits were being rebuilt. However, it was possible to place the electron gun on another ultrahigh vacuum system and to check out its general operating performance.

We have experienced no difficulty in operating this electron gun at 20 kV. As with all high voltage systems there is an adjustment period after a long down time or after the system has been opened to the atmosphere for service or repair. Under these conditions some high voltage discharging and instability may be noticed, but it will usually clear up in a short time and then stable operation can be expected.

The electron gun controls were found adequate to both align the optical column and to focus the beam on a fluorescent screen, which was placed at the same distance away from the cathode as the target crystal would be in the IFLM.

To obtain an accurate measurement of the electron beam size at the target would require additional sophisticated test equipment which we did not have at our disposal. We did, however, endeavour to measure the beam size by sweeping the beam off the edge of the fluorescent screen (target) at a known rate and observing the current decay on an oscilloscope. The data we obtained by this method indicated that the most finely focussed beam was approximately .0017 inch in diameter. If one subtracts edge diffraction effects and other fringing effects, the actual beam size appears to be a little over the design size of 0.001 inch diameter. There appears to be no reason why the beam could not be reduced to meet, or exceed, the design specification after suitable experience has been gained in the operation of this electron gun.

The design called for a beam current density of 2 Acm^{-2}, which is equivalent to a beam current of 1.013×10^{-5} A in a beam spot of 0.001 in diameter. We have not yet been able to demonstrate this high a current density in the focussed electron beam. With a 400 micron beam defining aperture in the anode we have measured beam currents in the vicinity of 10^{-6} A (corrected for backscatter). This is about an order of magnitude off the design estimate.

Although the maximum beam current that we have measured to date is not as high as we would like, it is close enough to the desired figure as to give us confidence that the design figure will be reached under more favorable operating conditions.

We have experienced two problems in trying to obtain higher beam currents, and these are the following. About the vacuum test station we have been using to evacuate the electron gun there are leakage magnetic fields from the VacIon pump. The two layers of Conetic shielding we have placed around the outside of the electron gun does not appear to be sufficient under the existing conditions. This problem has been experienced previously with this pumping system, and was eliminated when the electron optical equipment was moved to other systems. The current capacity of the Spellman 20 kV supply also limits the available beam current since we can easily draw the maximum current outputs and trip the overload relay.

The magnetic interference problem should be eliminated when the electron gun is transferred to the IFLM as this unit does not employ vacuum pumps with strong magnets. Also, it is a simple matter to add more layers of modulating electronics were mounted directly on the outside of the high voltage bushing.

As a point of interest it was found that this reentrant cathode assembly could be driven to shutoff by a 100 volt change in the voltage applied to the Wehnelt shield. The biasing voltage for maximum beam intensity was measuredto be approximately 19.5 kV, using a VTVM with a high voltage probe.

VI. MAINTENANCE OF ELECTRON OPTICAL COLUMN

A. General

The only parts of this column that will require periodic maintenance are the tungsten cathode and the three beam defining apertures which are located in the anode, modulator and lens No. 2. All these items are readily accessible once the lens tube has been removed from the vacuum housing.

It cannot be stressed too strongly that this electron gun was designed to operate in ultrahigh vacuum and thus all contaminating materials must be excluded from the system. Lint and dust particles can prove to be particularly troublesome since the electrical insulation for 20 keV operation has been kept to a minimum, and these foreign materials can cause repeated sparkovers which may result in permanent damage to the insulators. When handling cleaned gun components always wear lint-free nylon gloves or latex finger cots. Immediately before resealing the system be sure to blow off all components in and on the lens tube with a fine jet of high pressure (about 40 to 50 psi) dry tank nitrogen.

1. Final Cleaning of Gun Component Parts. All metal components that have been removed from the electron gun should be recleaned by the following procedure before they are replaced:

a) vapor degrease in trichloroethylene;

b) electroclean in a solution containing 7.5 gm of trisodium phosphate (Na_3PO_4) per liter of distilled water; use power from a 12 volt d.c. battery charger, making the work negative; several minutes is usually sufficient;

c) immediately transfer work from electrocleaner to ultrasonic cleaner, using a dilute solution of MICRO®* in this unit.

d) rinse with distilled water, then methanol and dry in a stream of dry nitrogen.

Should any of the non-metallic parts of the column need cleaning, e.g., Teflon parts and Teflon insulated wires, boron nitride insulators, and sapphire insulators, the same procedure as outlined above is used, except the electrocleaning step is deleted.

B. Filament Replacement

The filament assembly D and adaptor R, see Fig. 8b, can easily be removed as a unit through the rectangular port in the lens tube. All that is necessary to accomplish this is to loosen the screw holding the retaining clip in housing, Q, and after the clip is slid out of housing, Q, slide the assembly, RD, sideways by applying pressure to the side opposite the retaining clip.

If a prealigned cathode assembly is to be installed, all that is necessary is to remove the old unit by releasing the set screw in item, R, and pulling the two units apart. The replacement unit, D, is then simply plugged in and locked by the set screw.

In the event that only a new filament is being installed, the old filament has to be removed from the Wehnelt shield and the new filament plugged into position. The tip of the filament must be centered in the hole in the Wehnelt by using the four lateral adjusting screws, and after this has been accomplished the clamp ring is tightened.

Replacing the assembly, RD, is the reverse of the removal process described above.

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*International Products, Incorporated, Trenton, New Jersey.

C. Aperture Replacement

1. Anode Aperture. In order to remove the anode aperture the whole anode assembly has to be unscrewed from its housing in lens No. 1. Before this removal can commence the cathode assembly has to be removed, as outlined in section B above.

Once the anode assembly has been removed from lens No. 1 the beryllium copper aperture retaining screw is taken out of the anode and the platinum alloy aperture removed. In the event of the aperture being stuck in its recess, a small wooden tooth pick can be inserted from the far end to push the aperture out. It should be replaced with a new 400 micron Siemens type aperture. However, before inserting the new aperture the anode and retaining screw should be cleaned. Should any contamination be visible on the anode, it will be necessary to remove it with a little 6 micron diamond paste on a cotton swab. Before going through the final cleaning steps, see section A1 above, it will be necessary to remove the diamond paste etc. in the ultrasonic bath.

2. Modulator Aperture. To reach this aperture, the whole modulator assembly has to be withdrawn from the lens tube. This is accomplished by undoing the two retaining bolts, which also hold lens No. 2 aperture in place on lens No. 2 housing, and the two screws holding the electrical plug onto the lens housing. The whole modulator assembly can then be tilted to one side and withdrawn through one of the four holes provided for this purpose.

The modulator aperture is removed from the modulator housing by unscrewing the retaining cap and then pushing the aperture free as described in the section on anode aperture replacement. The part of the retaining cap that is exposed to the electron beam may also be contaminated, and, if this is the case, it will also require cleaning with diamond paste before final cleaning and replacing on the modulator. Be sure the replacement aperture is 750 microns.

When replacing the electrical connection plug in the lens tube be sure to line up the pins, see scribe line, so that the proper connection can be made to the vacuum feedthrough.

3. Lens No. 2 Aperture. This large stainless steel aperture is removed at the same time as the modulator. Since the direct electron beam rests on the face of this aperture during a reasonable part of the gun's operation, it is most probable that this aperture will contaminate at about the same rate as the anode aperture. Since the electron beam is continually being deflected away from the beam axis at this point by the modulator, any change effects resulting from a contamination layer on this aperture surface will be asymmetrical to the beam axis. The result will be distortions in the image on the target crystal.

Both the bore and top face of this aperture must be periodically cleaned with 6 micron diamond paste on a cotton swab, and then given a final cleaning as previously outlined in this report.

VII. CONCLUSIONS AND RECOMMENDATIONS

A 20 keV electron gun has been designed and fabricated to serve as the write gun for the engineering model of the IFLM, which was developed under Contract NA58-27375. This gun has been demonstrated to operate at TV picture framing speeds, although the beam current density has so far been somewhat lacking. It is anticipated that the current density in the beam can be improved to equal that of the design specifications.

For the few hours of operating time that this electron gun has been evaluated, it has performed extremely well and no serious problems have developed. It should give long and reliable service in the instrument for which it was designed.

It still remains to be demonstrated that electrostatic deflection of the beam will be a suitable method for modulating an electron beam at 4 MHz. In the event that this method of beam modulation not prove to be feasible, it is still within the present design concept to revert to beam modulation by altering the Wehnelt shield potential.

Several new design concepts have been tried in this system, and they have proved to be quite successful in this type of electron gun. The designs in question are those used in the electrostatic lenses and in the linear adjustment of the cathode assembly with respect to the electron optical column axis.

Both systems have been found to be functional, but could entertain a certain amount of redesign before being considered suitable for general usage. In the case of the einzel lenses, practice has shown that it would be preferable to use screws to attach the removable electrode to the housing rather than the screw threads currently being used. Also, it would be preferable to eliminate the Teflon spacers in these lenses and use stop bolts on either side of each alumina sphere. This modification would greatly ease the assembling of these lenses and make for an overall better design.

Although the cathode adjustment mechanism works in principle, it is rather stiff and jerky to operate. It would function more smoothly if the sliding surface area was reduced and either a solid lubricant or dissimilar metals were used on the bearing surfaces. Either solution should prove to be satisfactory.

Basically, this type of electron gun design appears to be ideally suited to this type of application and should lend itself to further development in this area of electro-optical instrumentation. Should higher beam current densities become necessary in future applications, the thermionically emitting tungsten filament could be replaced with a lanthanum hexaboride emitter or even a field-emitting tungsten emitter. Either of these alternatives will require a considerable amount of design work in order to make them practical in this type of design.

VIII. ACKNOWLEDGEMENTS

The successful completion of this project would not have been possible without the willing help of many persons in the Engineering Experiment Station. Special mention should be made of the untiring way in which Mr. J. W. Elder carried out the arduous task of preparing the complete set of working drawings for this electron gun, and to Mr. L. A. Phillips for constructing the electronic packages, as well as performance testing the completed unit. Finally, the Mechanical Services Group should be acknowledged for the excellent way in which they carried out the fabrication of the many intricate parts of this electron gun.

IX. REFERENCES

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4. P. Grivet, ibid., page 573 (1972).

5. M. E. Haine, "The Electron Microscope," E. and F. N. Spon, London, page 21 (1961).

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X. APPENDIX A

Contained herein is a listing of the engineering drawings and reproductions of these drawings.

Drawing Title		Drawing Number	Page
Fig. A1.	Assembly, complete electron gun	A1558-1A	
Fig. A2.	Cathode sub-assembly	A1558-1B	
Fig. A3.	Top flange-welded assembly	A1558-1-01	
Fig. A4.	Top flange	A1558-1-01-001	
Fig. A5.	Pin, receptable-fluted insulator	A1558-1-01-002	
Fig. A6.	Welded assembly-vacuum housing	A1558-1-02	
Fig. A7.	End cap-vacuum housing	A1558-1-02-001	
Fig. A8.	Main tube-vacuum housing	A1558-1-02-002	
Fig. A9.	Tube, mounting-adjuster	A1558-1-02-003	
Fig. A10.	Shield, abrasion-coil	A1558-1-02-004	
Fig. A11.	Modification, connector flange	A1558-1-02-005	
Fig. A12.	Tube, flange-connecting port	A1558-1-02-006	
Fig. A13.	Magnetic shield-upper, short	A1558-1-02-007	
Fig. A14.	Magnetic shield-upper, long	A1558-1-02-008	
Fig. A15.	Magnetic shield-lower	A1558-1-02-009	
Fig. A16.	Flange, mounting-linear adjustment	A1558-1-03-001	
Fig. A17.	Plunger,bellows-linear adjustment	A1558-1-03-002	
Fig. A18.	Bellows assembly-linear adjustment	A1558-1-03-003	
Fig. A19.	Collar, weld-outside bellows assembly (not used in final assembly)	A1558-1-03-004	
Fig. A20.	Collar, weld-inside bellows assembly (not used in final assembly)	A1558-1-03-005	
Fig. A21.	Bushing, slide rod bushing-linear adjustment	A1558-1-03-006	
Fig. A22.	Cap, slide rod bushing-linear adjustment	A1558-1-03-007	
Fig. A23.	Bar, slide-linear adjustment	A1558-1-03-008	
Fig. A24.	Cap, slide flange-linear adjustment	A1558-1-03-009	
Fig. A25.	Knob, adjustment-linear adjustment	A1558-1-03-010	
Fig. A26.	Pin, torque react-linear adjustment	A1558-1-03-011	
Fig. A27.	Disc, housing support-filament mounting assembly	A1558-1-04-001	
Fig. A28.	Ring, retaining-filament mounting assembly	A1558-1-04-002	
Fig. A29.	Housing-filament mounting assembly	A1558-1-04-003	
Fig. A30.	Adapter, plug-in-filament mounting assembly	A1558-1-04-004	
Fig. A31.	Bushing, contact-filament mounting assembly	A1558-1-04-005	

Drawing Title		Drawing Number	Page
Fig. A32.	Nut, insulator stud-filament mounting assembly	A1558-1-04-006	
Fig. A33.	Spring, adjust return-filament mounting assembly	A1558-1-04-007	
Fig. A34.	Spring, contact-filament mounting assembly	A1558-1-04-008	
Fig. A35.	Clip, retainer-filament mounting assembly	A1558-1-04-009	
Fig. A36.	Terminal, lens high voltage lead-filament mounting assembly	A1558-1-04-010	
Fig. A37.	Insulating bushing-filament mounting assembly	A1558-1-04-011	
Fig. A38.	Assembly-lens mounting tube	A1558-1-05	
Fig. A39.	Tube-lens mounting	A1558-1-05-001	
Fig. A40.	Flange-lens mounting tube	A1558-1-05-002	
Fig. A41.	Screw, lens No. 1 adjustment	A1558-1-05-003	
Fig. A42.	Screw, lens No. 2 adjustment	A1558-1-05-004	
Fig. A43.	Retainer, modulator plug-lens mounting tube	A1558-1-05-005	
Fig. A44.	Connector, modulator plug-lens mounting tube	A1558-1-05-006	
Fig. A45.	Pin, modulator plug-lens mounting tube	A1558-1-05-007	
Fig. A46.	Assembly-lens No. 1	A1558-1-06	
Fig. A47.	Housing-lens No. 1	A1558-1-06-001	
Fig. A48.	Cap-lens No. 1	A1558-1-06-002	
Fig. A49.	Center electrode-lens No. 1	A1558-1-06-003	
Fig. A50.	Retainer, ball-lens No. 1	A1558-1-06-004	
Fig. A51.	Connector, center electrode-lens No.1	A1558-1-06-005	
Fig. A52.	Screw, ball stop-lenses No. 1 and No. 2	A1558-1-06-006	
Fig. A53.	Anode-lens No. 1 housing	A1558-1-06-007	
Fig. A54.	Aperture retainer-Anode	A1558-1-06-008	
Fig. A55.	Retainer, stigmator-lens No. 1 housing	A1558-1-06-009	
Fig. A56.	Ring, retainer-stigmator	A1558-1-06-010	
Fig. A57.	Housing, stigmator-lens No. 1 housing	A1558-1-06-011	
Fig. A58.	Pin-stigmator	A1558-1-06-012	
Fig. A59.	Electrical conductor-stigmator	A1558-1-06-013	
Fig. A60.	Housing-lens No. 2	A1558-1-07-001	
Fig. A61.	Cap-lens No. 2	A1558-1-07-002	
Fig. A62.	Center electrode-lens No. 2	A1558-1-07-003	
Fig. A63.	Aperture-modulator	A1558-1-07-004	
Fig. A64.	Aperture retaining nut-modulator (no drawing made)	A1558-1-07-005	
Fig. A65.	Plate-modulator	A1558-1-07-006	
Fig. A66.	Plate-modulator	A1558-1-07-007	
Fig. A67.	Housing-modulator	A1558-1-07-008	
Fig. A68.	Cap-modulator	A1558-1-07-009	

Drawing Title	Drawing Number	Page
Fig. A69. Connector-electron gun control	A1558-2-10-001	
Fig. A70. Assembly-high voltage plug	A1558-2-20	
Fig. A71. Washer-high voltage plug	A1558-2-20-001	
Fig. A72. Housing-high voltage plug	A1558-2-20-002	
Fig. A73. Top insulator-high voltage plug	A1558-2-20-003	
Fig. A74. Lower insulator-high voltage plug	A1558-2-20-004	

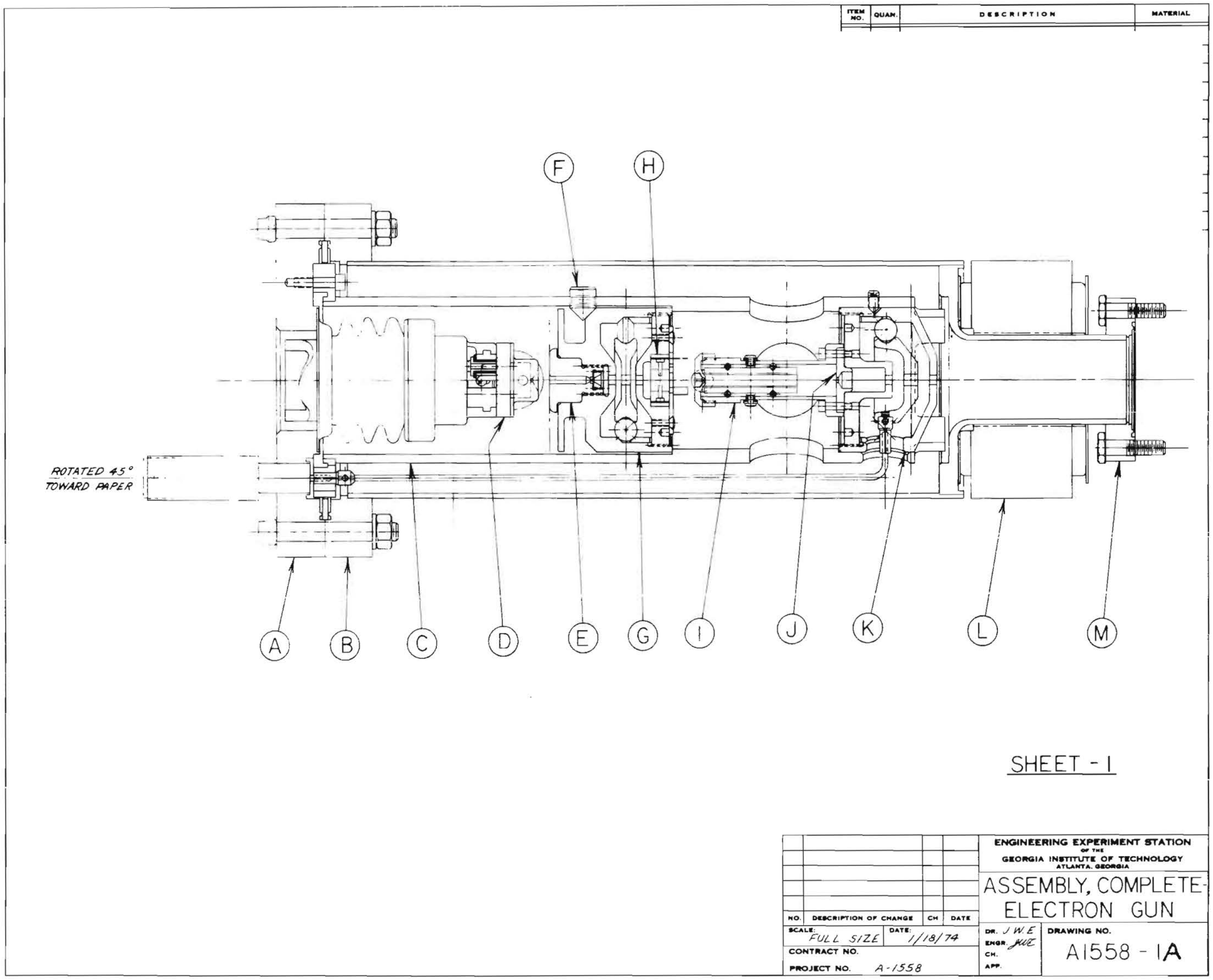


Fig. A1. Assembly, complete electron gun.

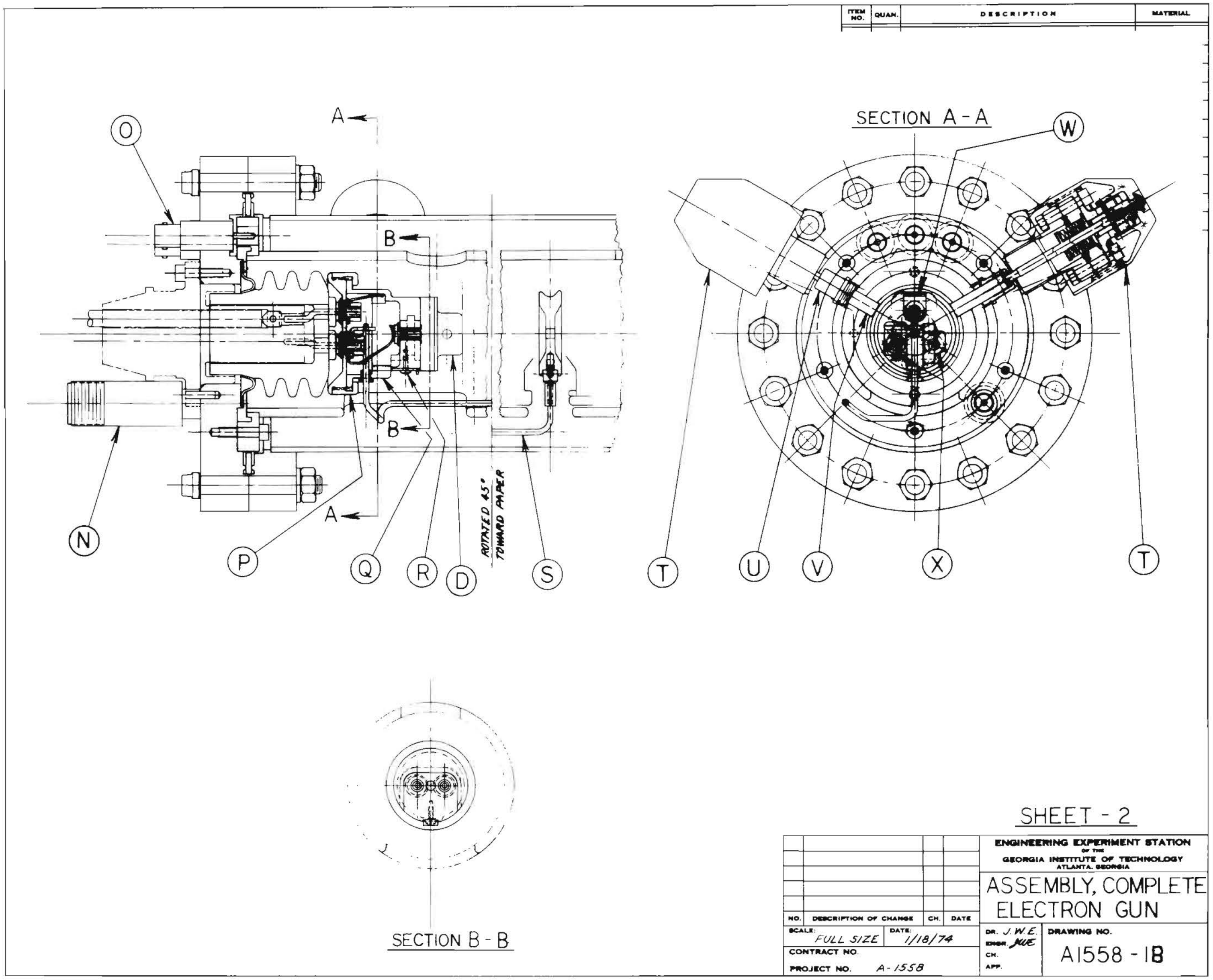


Fig. A2. Cathode sub assembly.

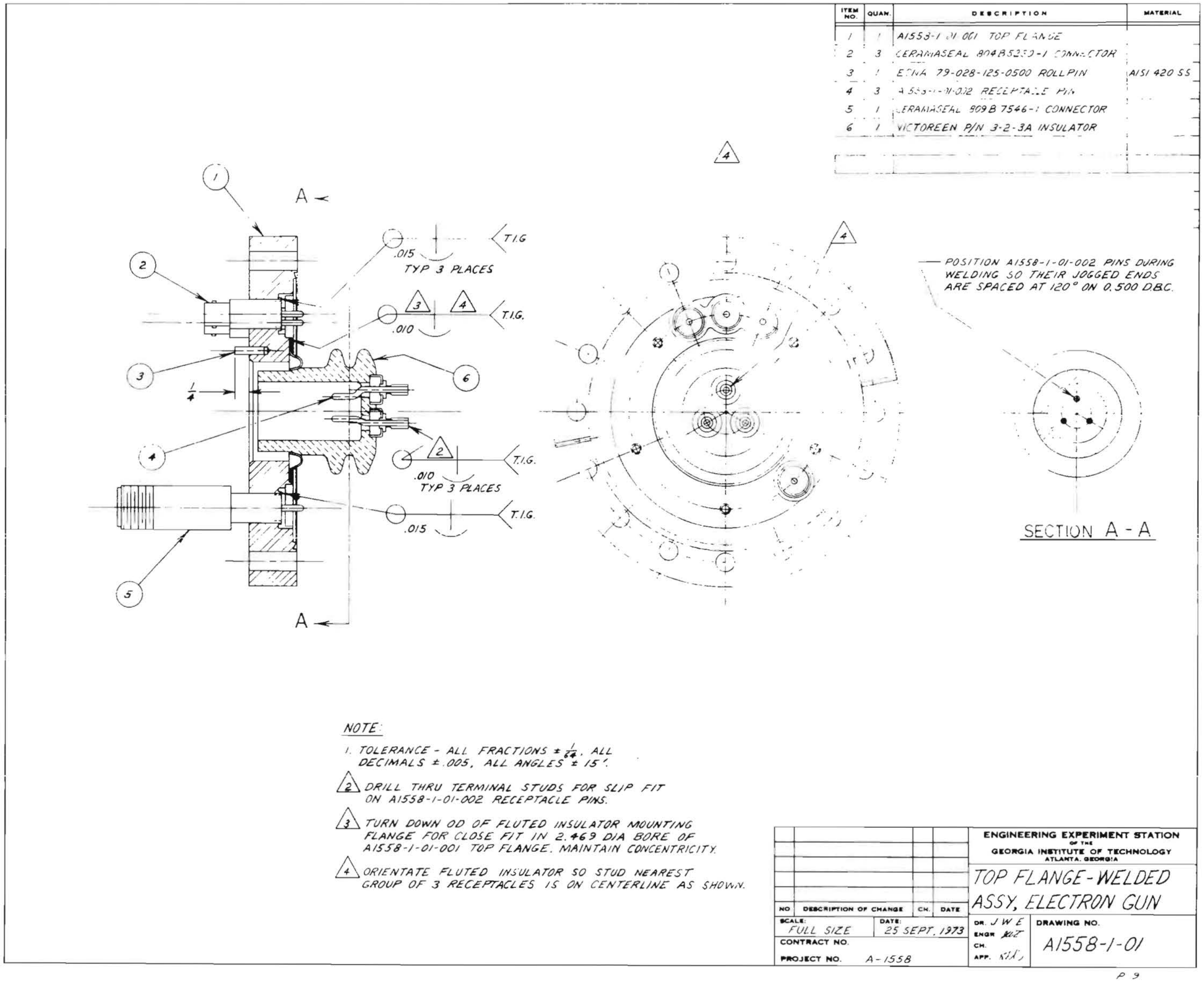


Fig. A3. Top flange-welded assembly.

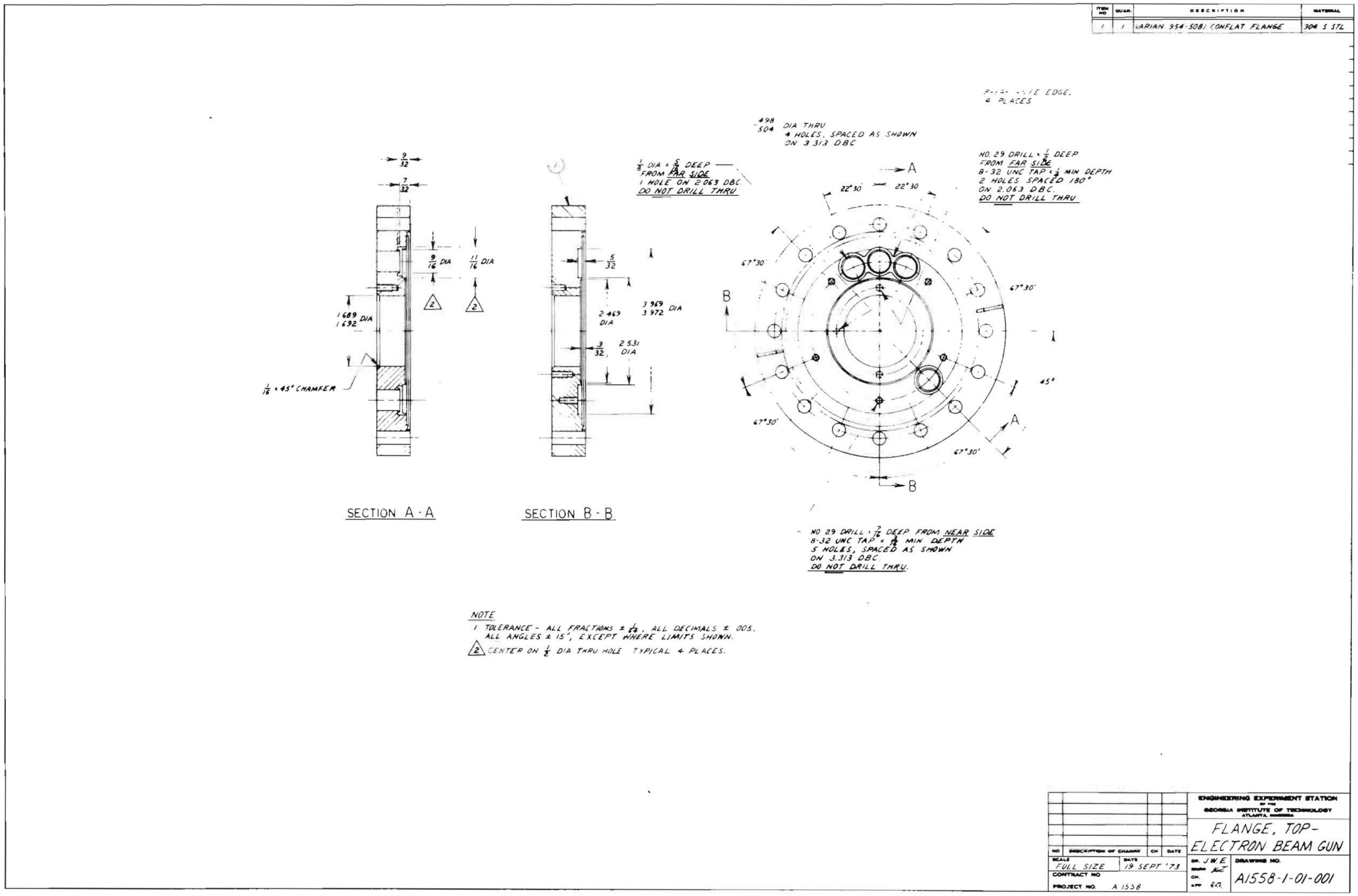
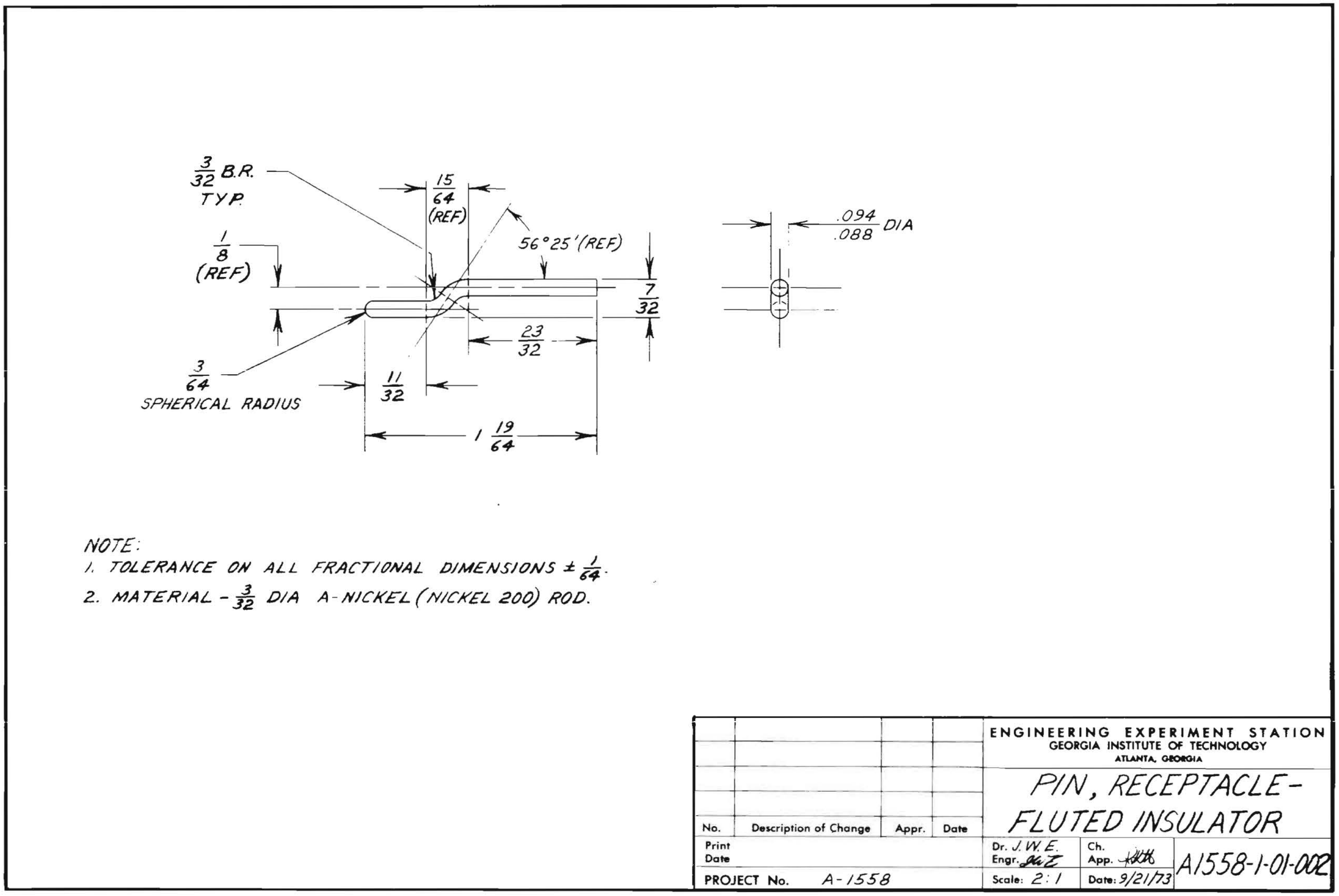


Fig. A4. Top flange.



P 9

Fig. A5. Pin, receptable-fluted insulator.

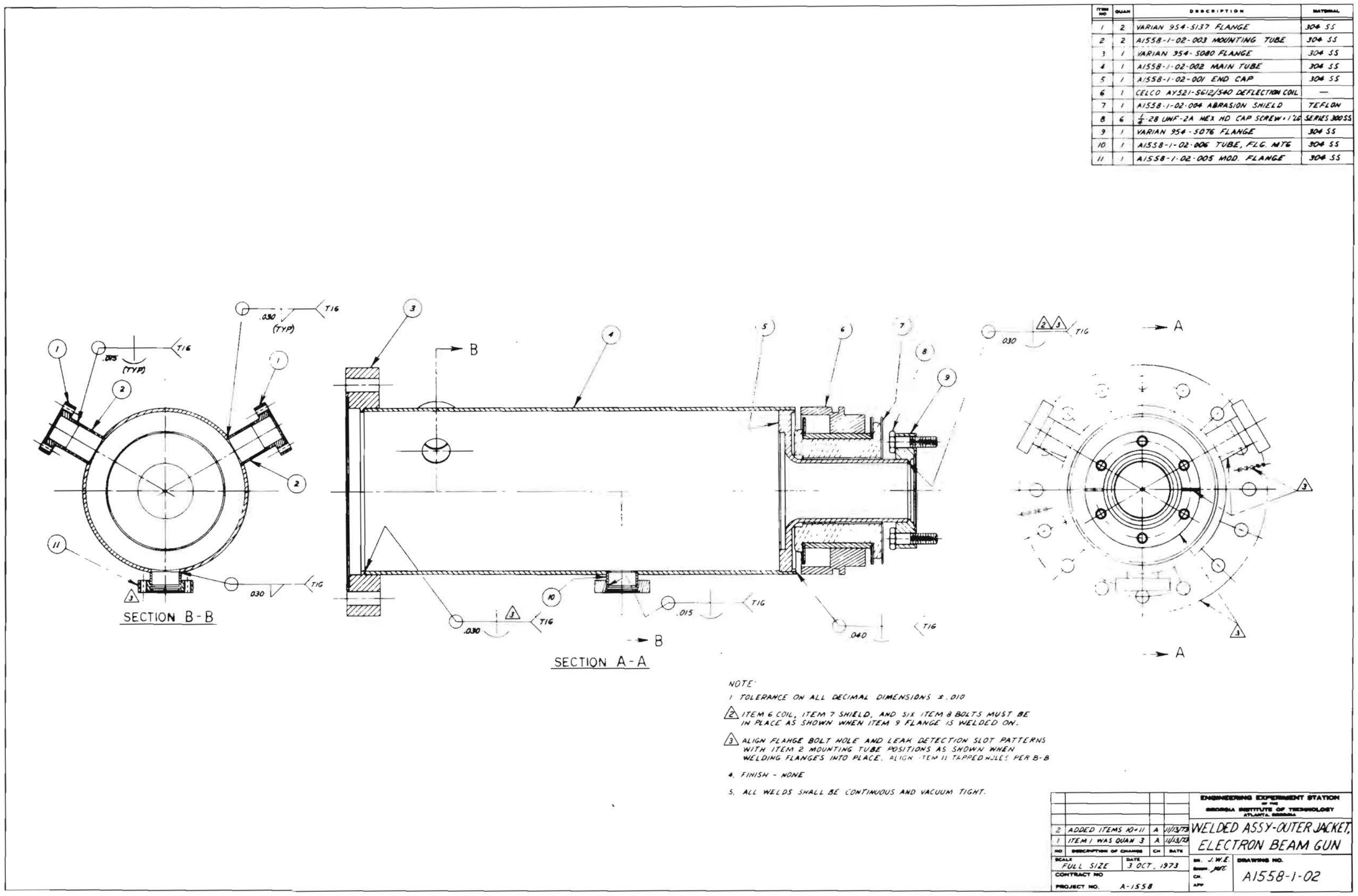


Fig. A6. Welded assembly-vacuum housing.

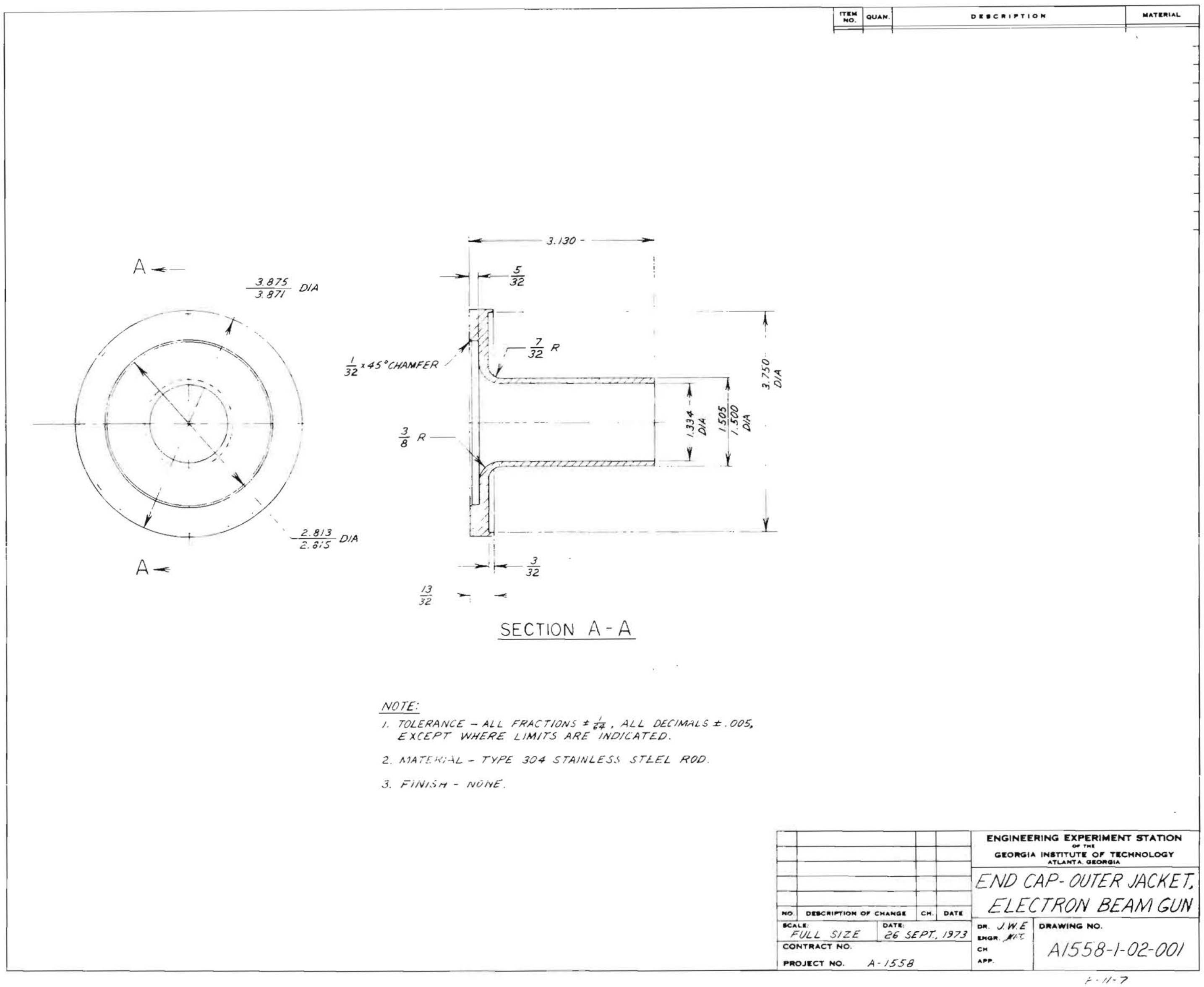


Fig. A7. End cap-vacuum housing.

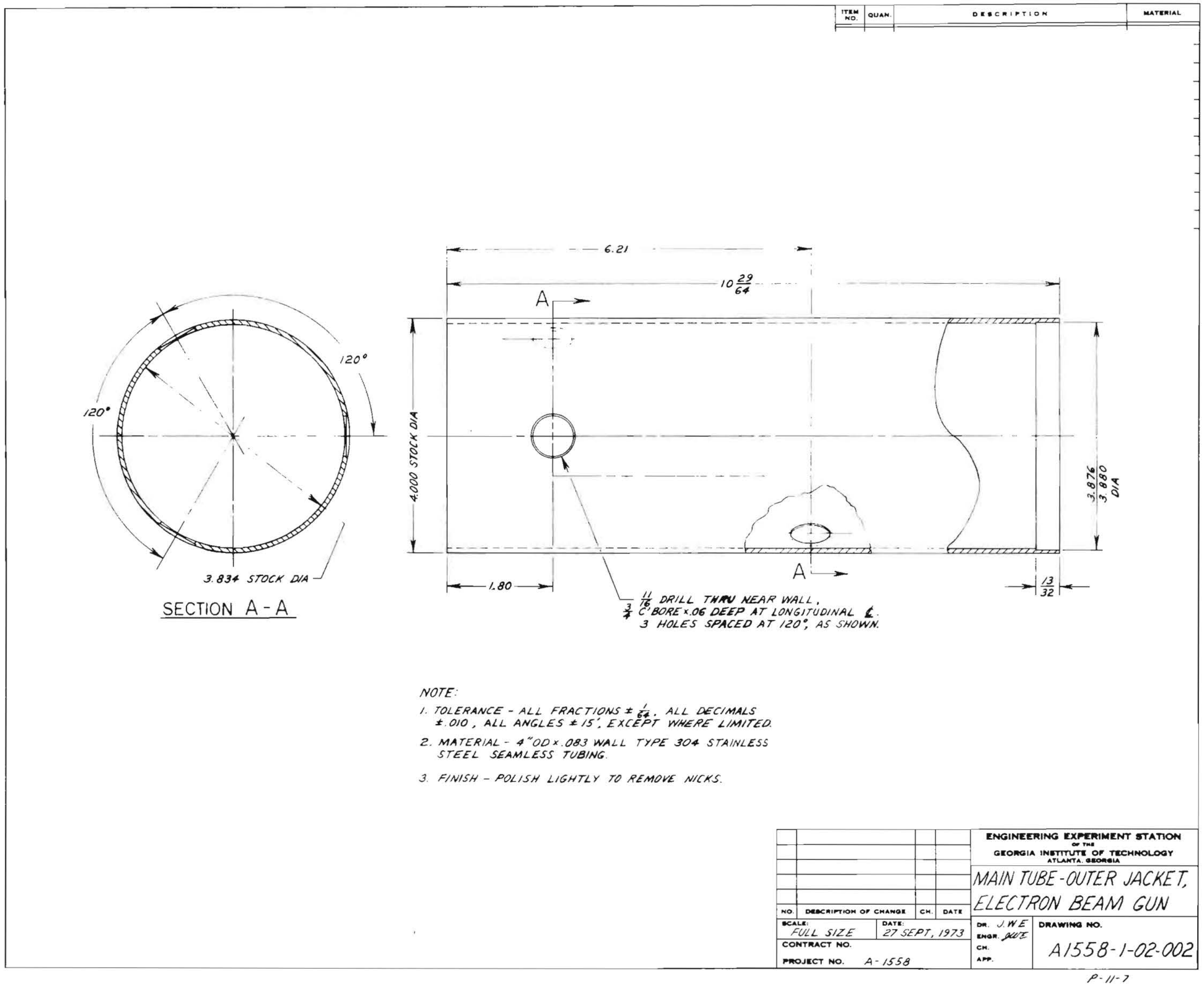


Fig. A8. Main tube-vacuum housing.

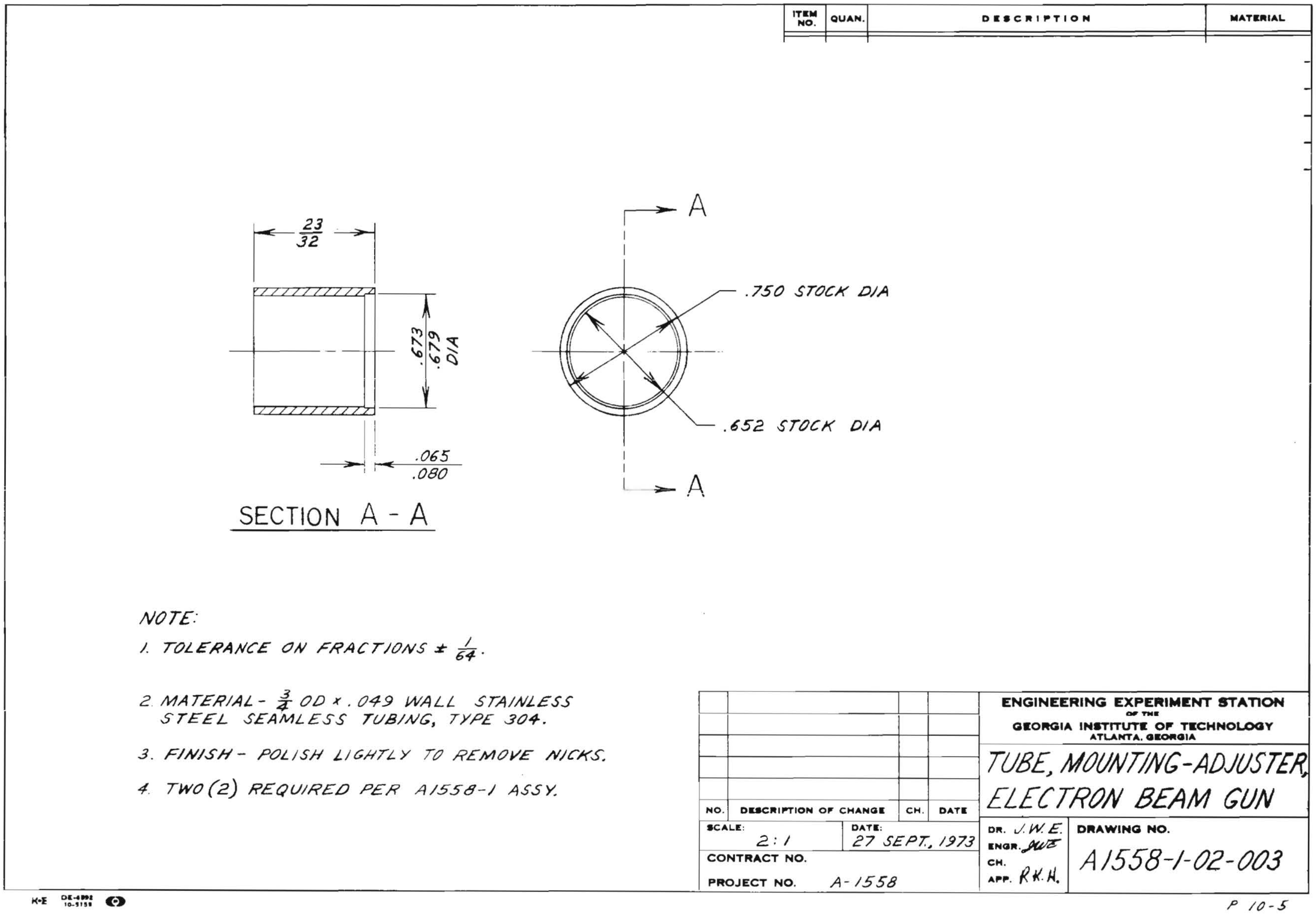


Fig. A9. Tube, mounting-adjuster.

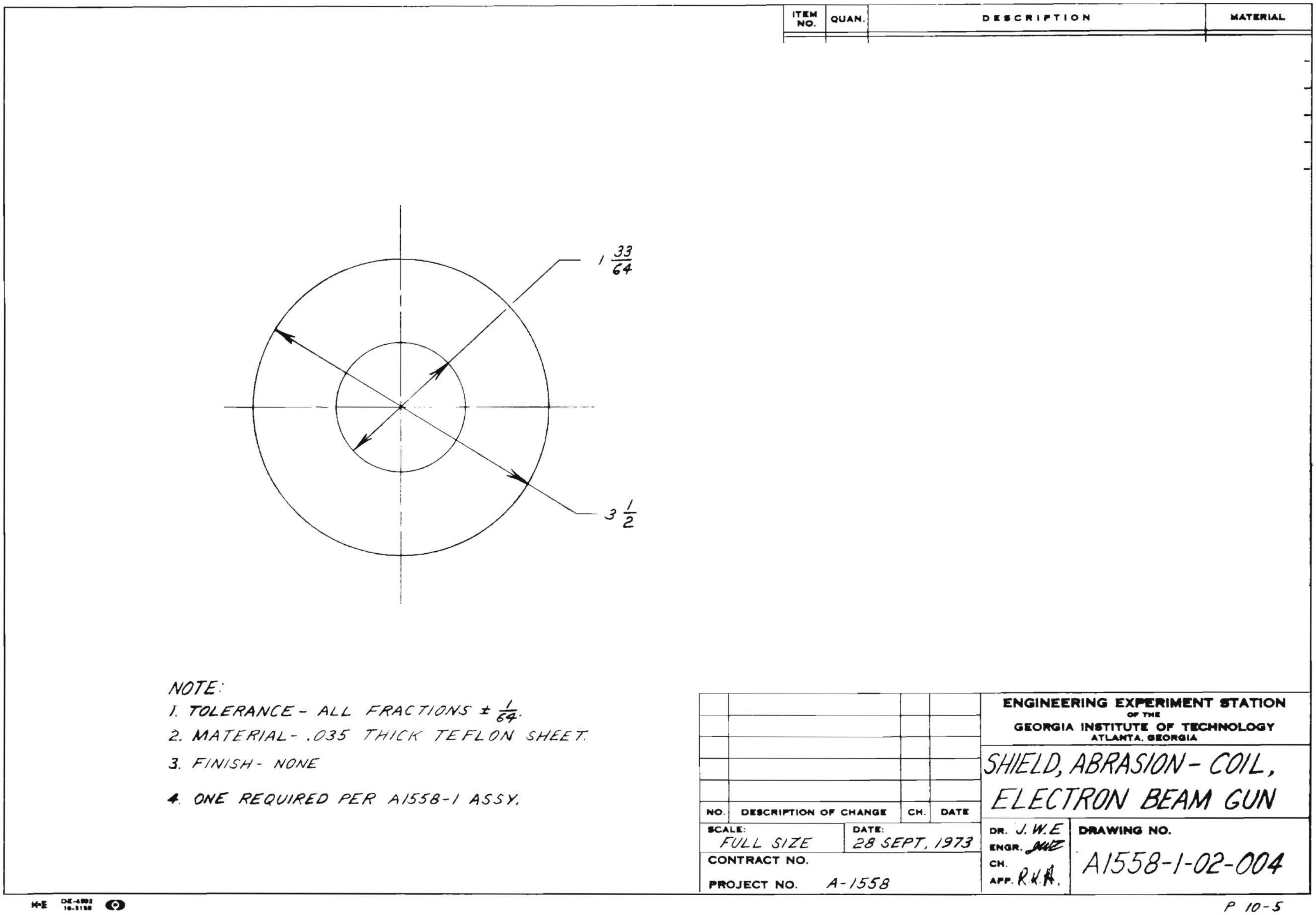
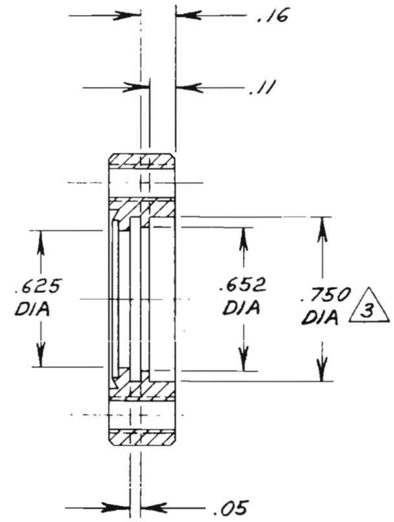


Fig. A10. Shield, abrasion-coil.



NOTE:

1. TOLERANCE- .XXX ±.005, .XX ±.010.
2. MATERIAL- VARIAN MODEL 954-5137 FLANGE.
3. DIA OF .11 DEEP BORE TO BE SLIP FIT ON OD OF A1558-1-02-006
4. FINISH - NONE
5. ONE (1) PART REQ'D. PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

MOD., CONNECTOR FLANGE-OUTER JACKET ASSY.

SCALE: 2:1
DATE: 13 NOV., 1973
CONTRACT NO.
PROJECT NO. A-1558

DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-02-005

H-E DE 7556 10-5155

P-11-14

Fig. A11. Modification, connector flange.

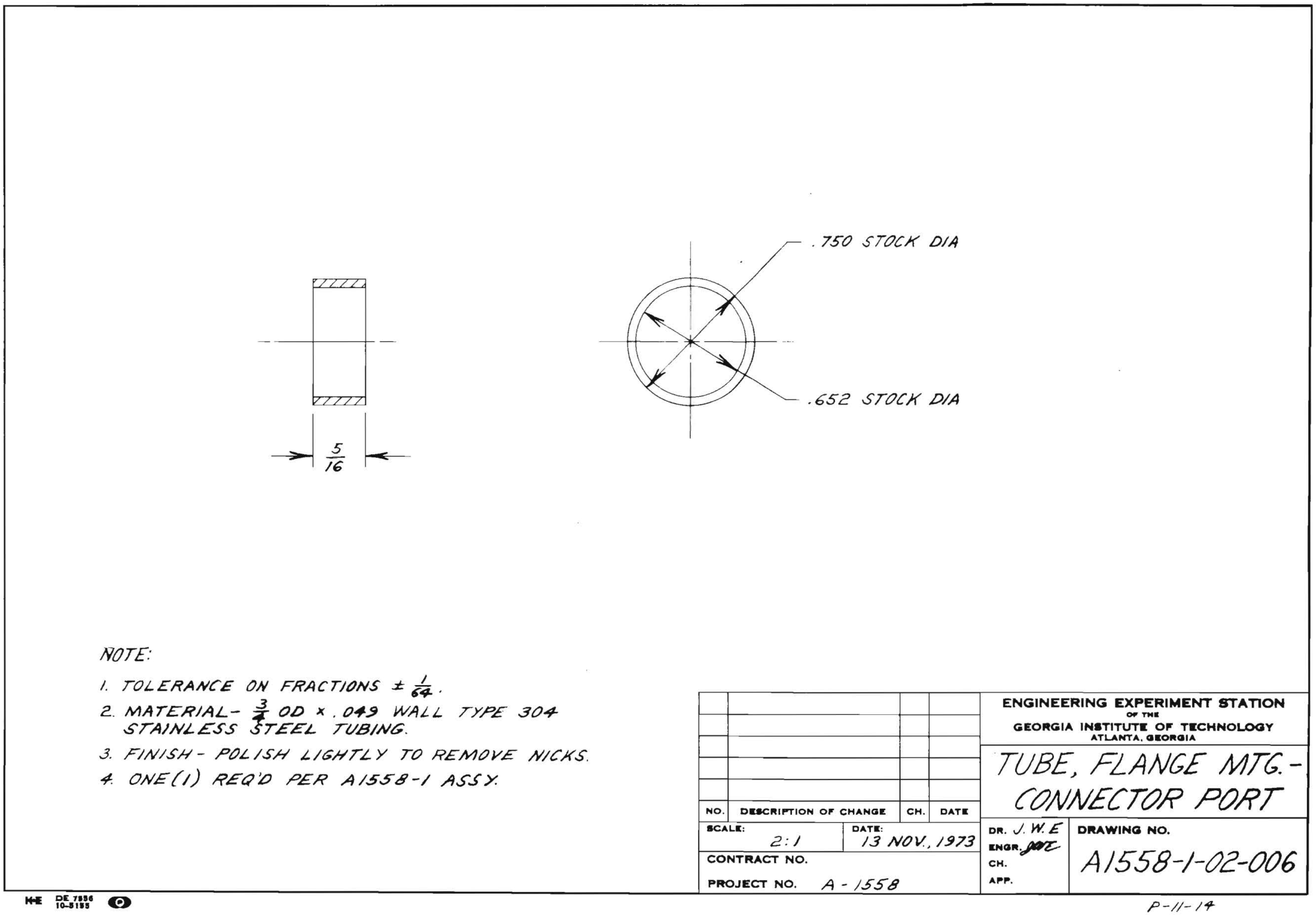


Fig. A12. Tube, flange-connecting port.

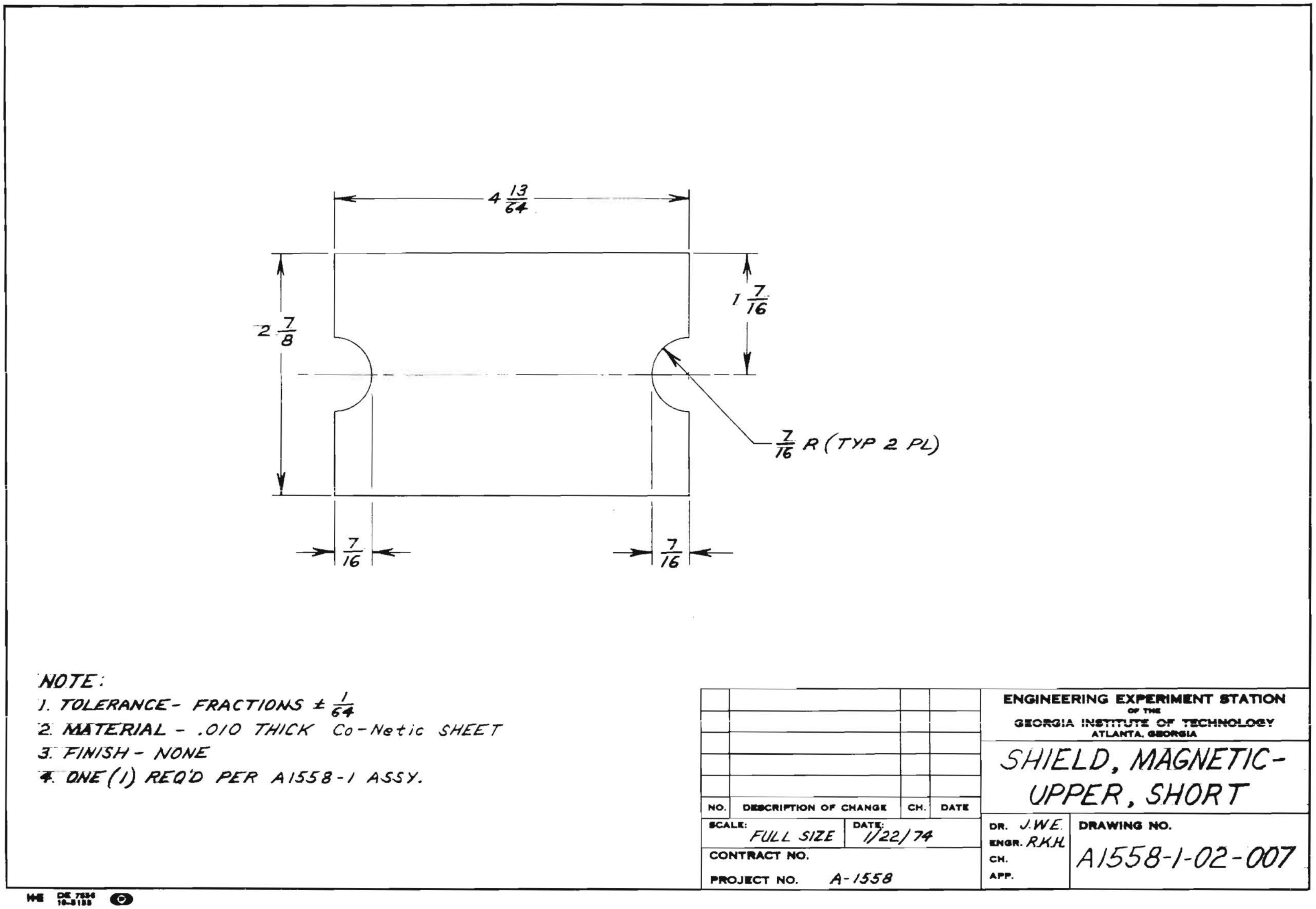


Fig. A13. Magnetic shield-upper, short.

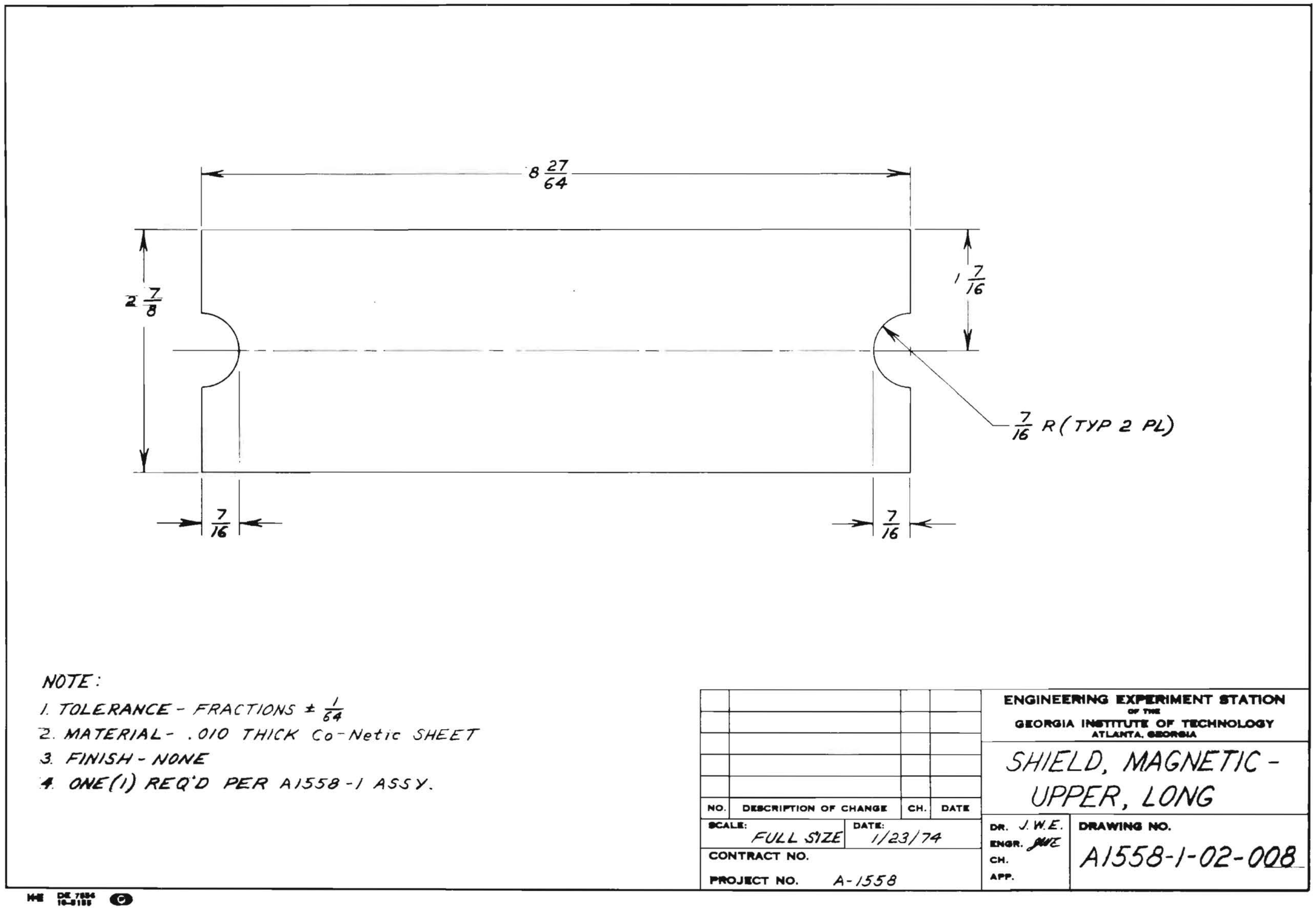


Fig. A14. Magnetic shield-upper, long.

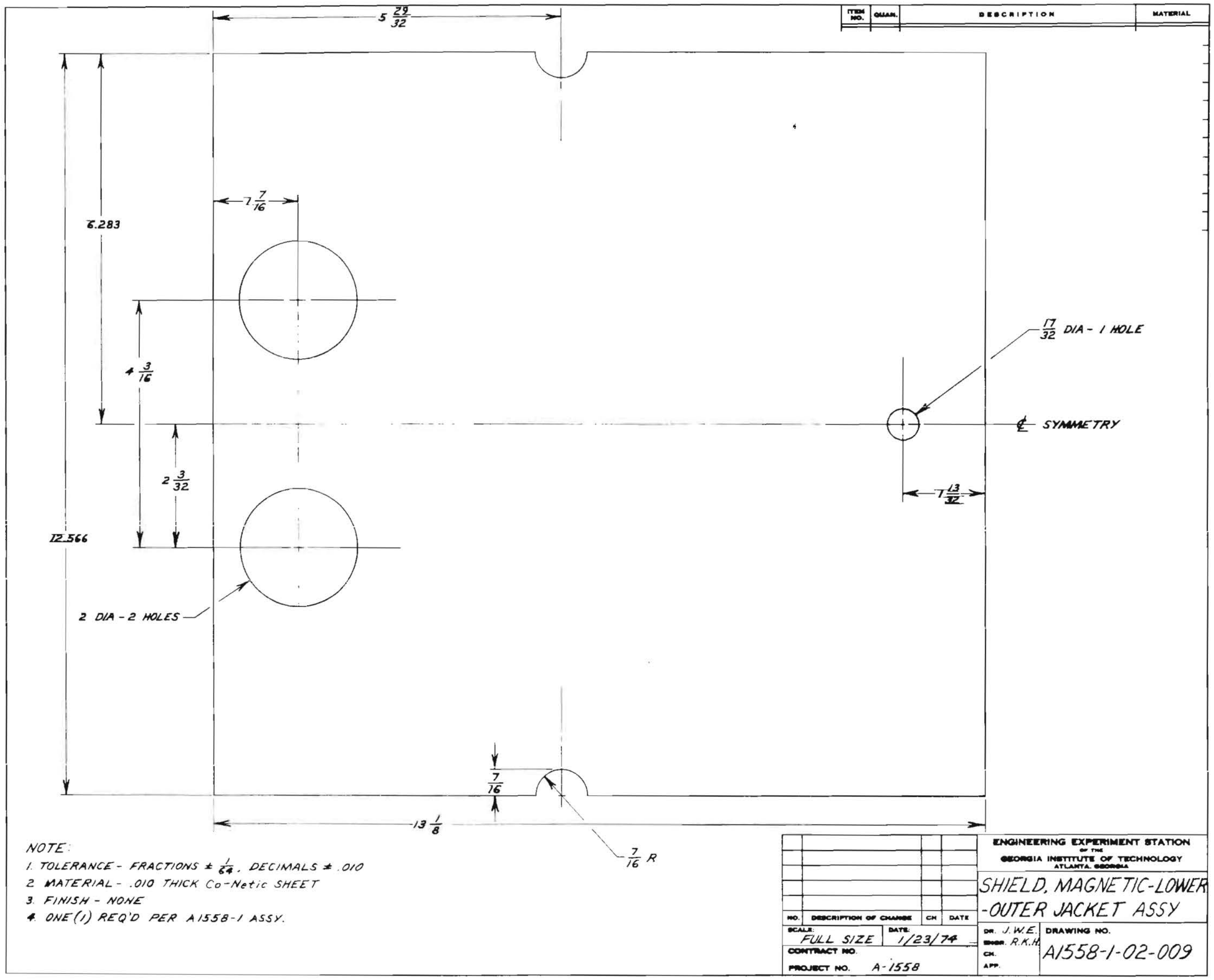


Fig. A15. Magnetic shield-lower.

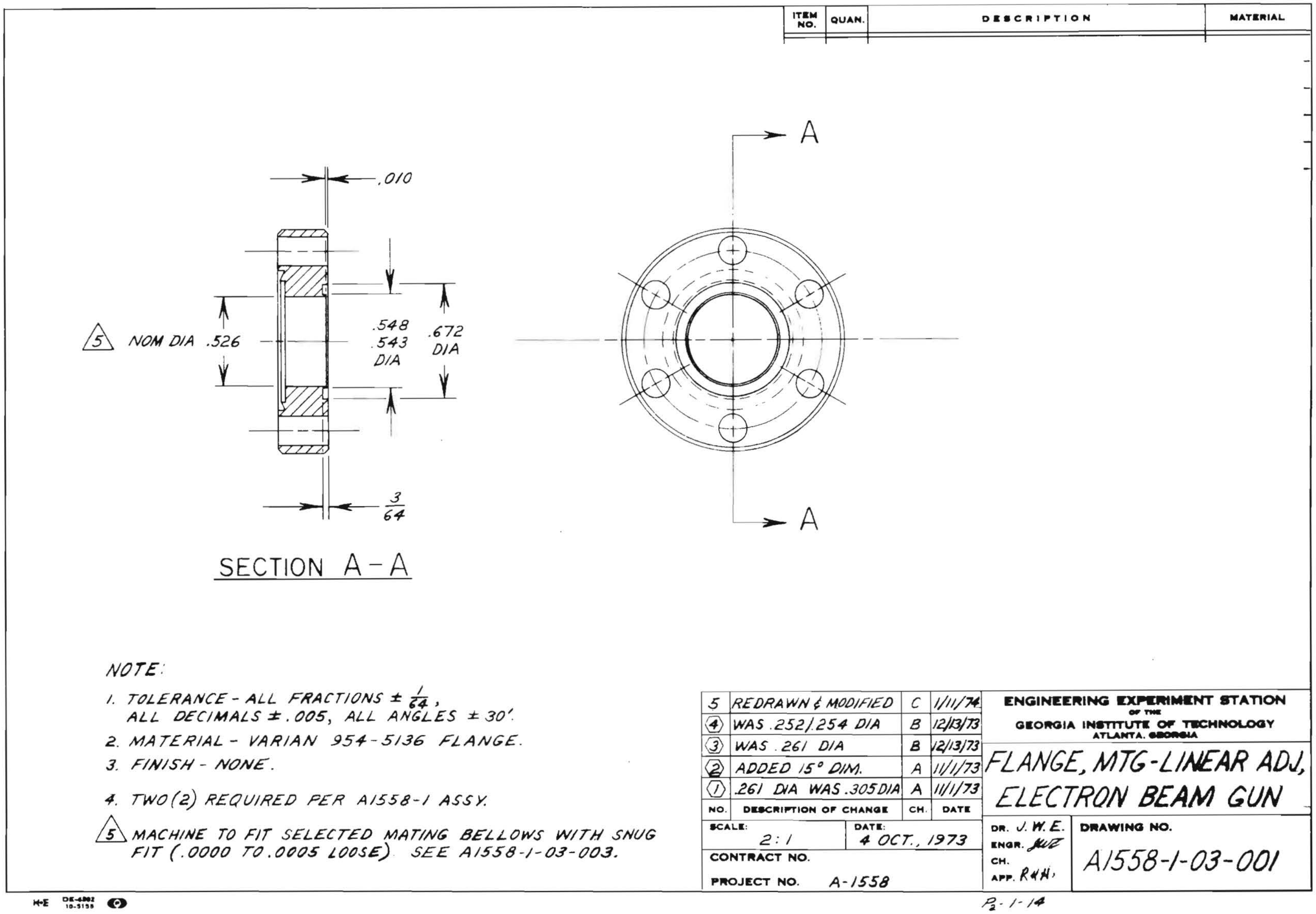


Fig. A16. Flange, mounting-linear adjustment.

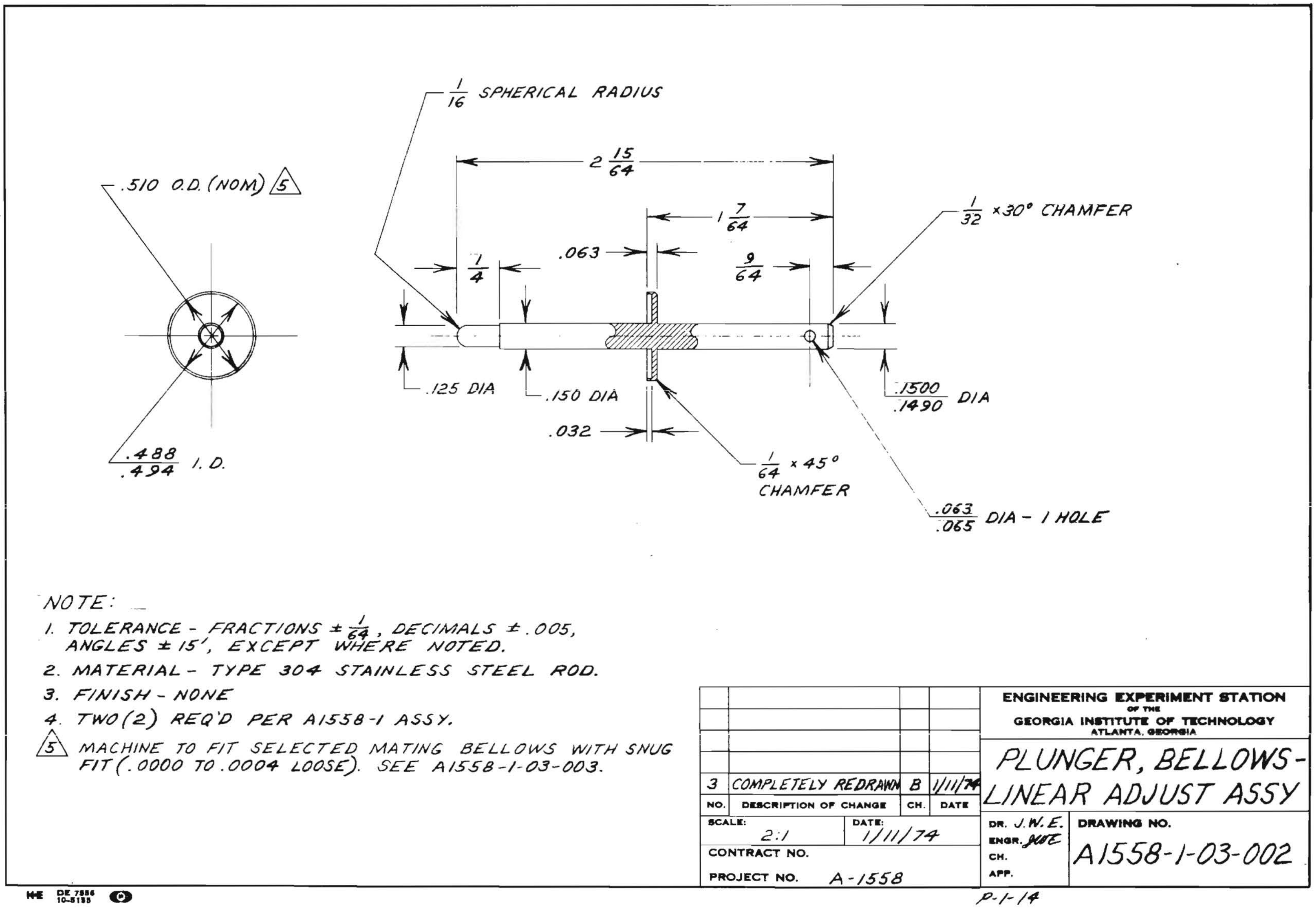


Fig. A17. Plunger, bellows-linear adjustment.

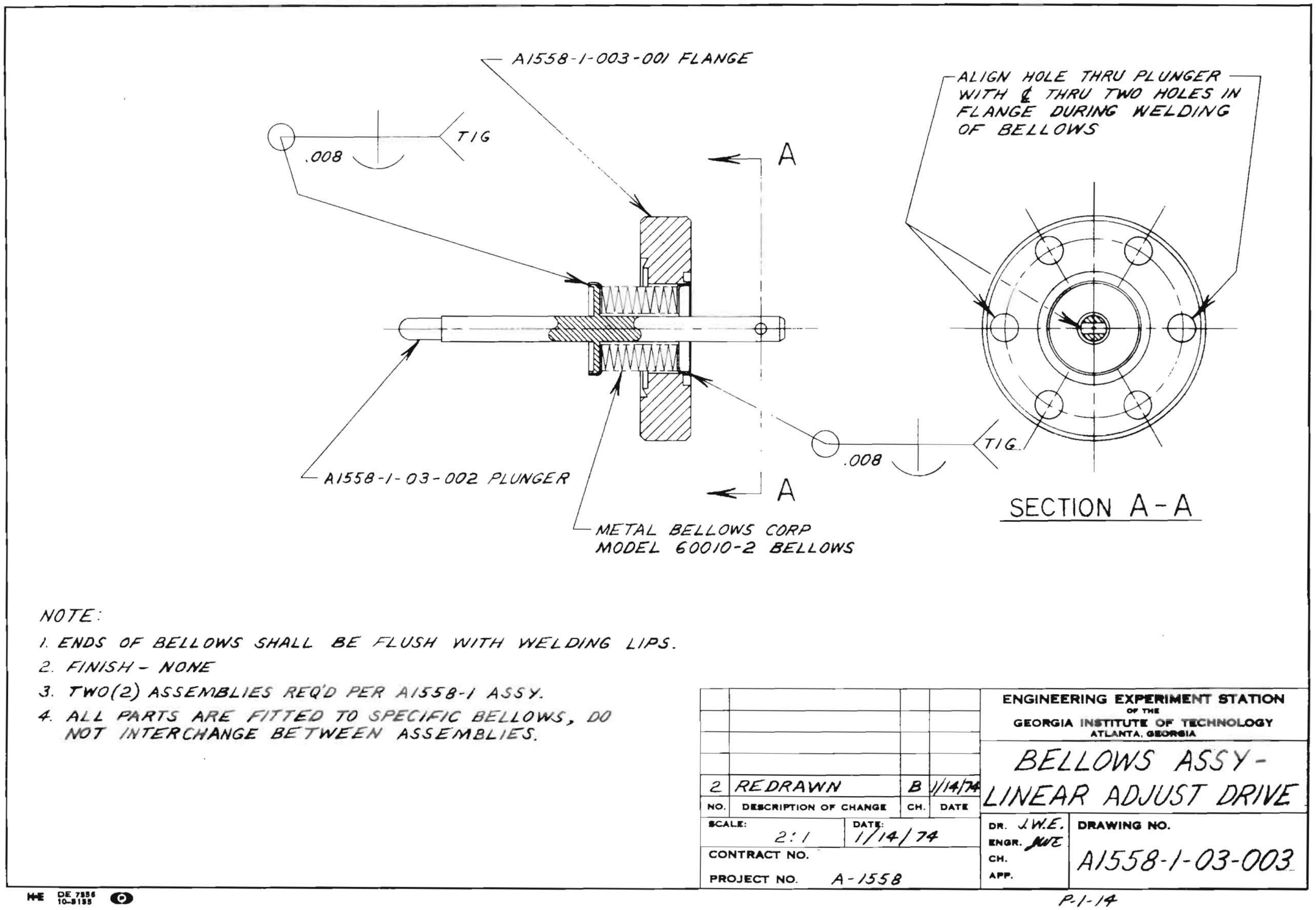
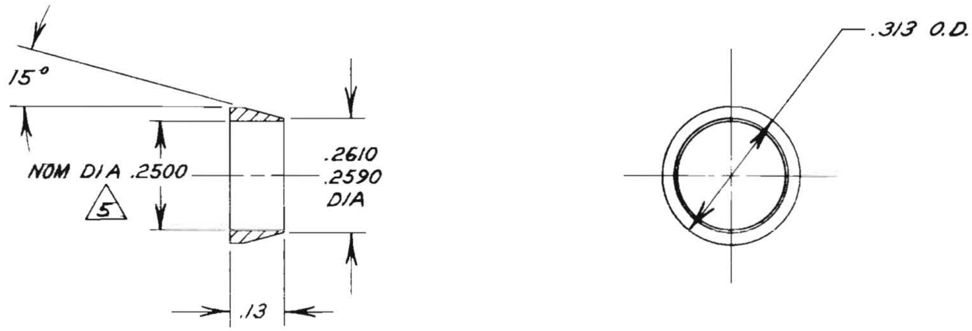


Fig. A18. Bellows Assembly-linear adjustment.



NOTE:

1. TOLERANCE - DECIMALS .XXX ±.005, .XX ±.010, ANGLES ±15′
2. MATERIAL - TYPE 304 STAINLESS STEEL
3. FINISH - NONE
4. TWO (2) REQ'D PER A1558-1 ASSY.

5 MACHINE TO FIT SELECTED MATING BELLOWS WITH SNUG FIT (.0000 TO .0005 LOOSE). SEE A1558-1-03-003.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

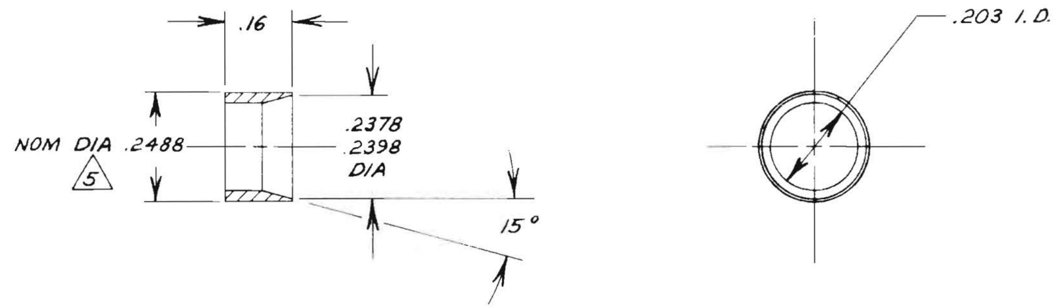
COLLAR, WELD-OUTSIDE, BELLOWS ASSY

SCALE: 4:1
DATE: 12/13/73
CONTRACT NO.
PROJECT NO. A-1558
DR. J.W.E.
ENGR. JWE
CH.
APP.
DRAWING NO. A1558-1-03-004

K+E DE 7856 10-5185

P-12-14

Fig. A19. Collar, weld-outside bellows assembly.



NOTE:

1. TOLERANCE - DECIMALS .XXX ± .005, .XX ± .010, ANGLES ± 15′
2. MATERIAL - TYPE 304 STAINLESS STEEL
3. FINISH - NONE
4. TWO (2) REQ'D PER A1558-1 ASSY.

△5 MACHINE TO FIT SELECTED MATING BELLOWS WITH SNUG FIT (.0000 TO .0004 LOOSE). SEE A1558-1-03-003.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: 4:1 DATE: 12/14/73

CONTRACT NO.

PROJECT NO. A-1558

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

COLLAR, WELD-INSIDE, BELLOWS ASSY

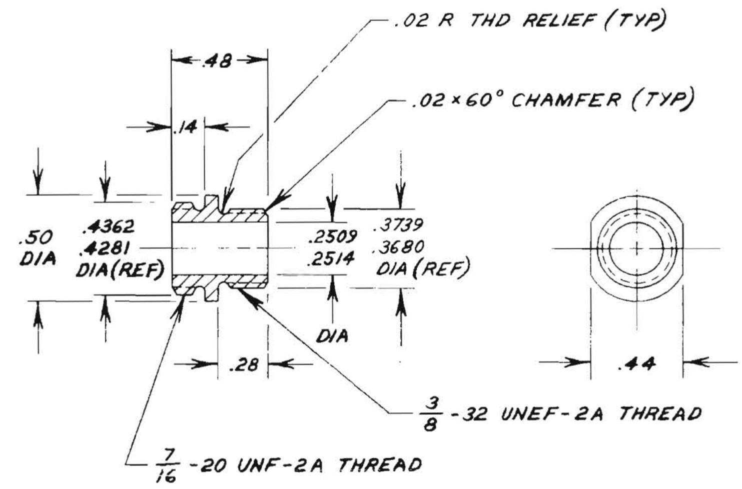
DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-03-005

K+E DE 7856 10-8185

P-12-14

Fig. A20. Collar, weld-inside bellows assembly.



NOTE:

1. TOLERANCE - DECIMALS .XX ± .010, ANGLES ± 1°, EXCEPT WHERE LIMITS ARE GIVEN.
2. MATERIAL - ALLOY 25 BERYLLIUM COPPER .50 DIA ROD
3. FINISH - NONE
4. TWO (2) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

BUSHING, SLIDE ROD-LINEAR ADJUST ASSY

SCALE: 2:1 DATE: 12/19/73
CONTRACT NO.
PROJECT NO. A-1558

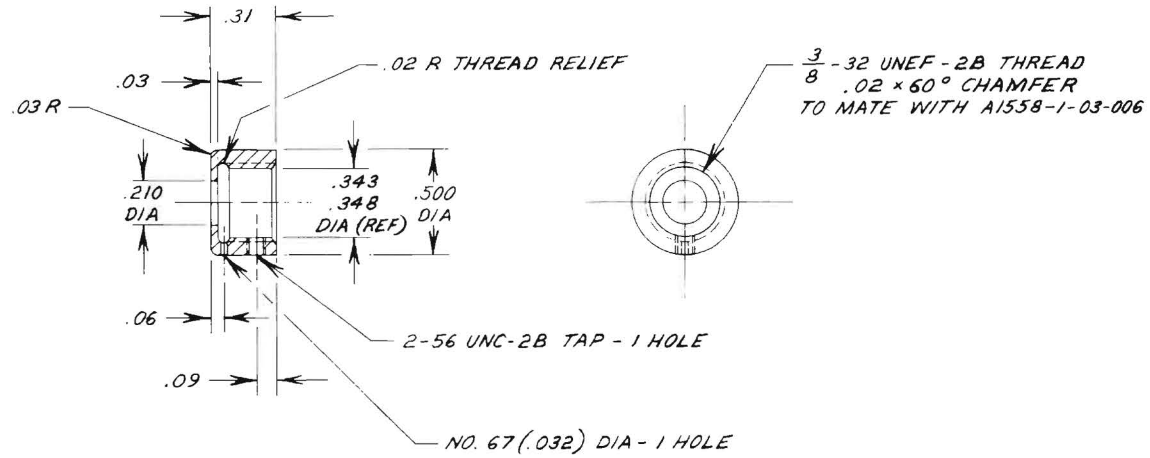
DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-03-006

H-E DE 7556 10-8155

P-12-20

Fig. A21. Bushing, slide rod bushing-linear adjustment.



NOTE:

1. TOLERANCE - DECIMALS .XXX ± .005, .XX ± .010, ANGLES ± 1°
2. MATERIAL - ALLOY 25 BERYLLIUM COPPER .500 DIA ROD
3. FINISH - NONE
4. TWO (2) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: 2:1 DATE: 12/20/73

CONTRACT NO.

PROJECT NO. A-1558

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

CAP, SLIDE ROD BUSHING-LINEAR ADJUST ASSY

DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-03-007

H-E DE 7556 10-5155

P-12-20

Fig. A22. Cap, slide rod bushing-linear adjustment.

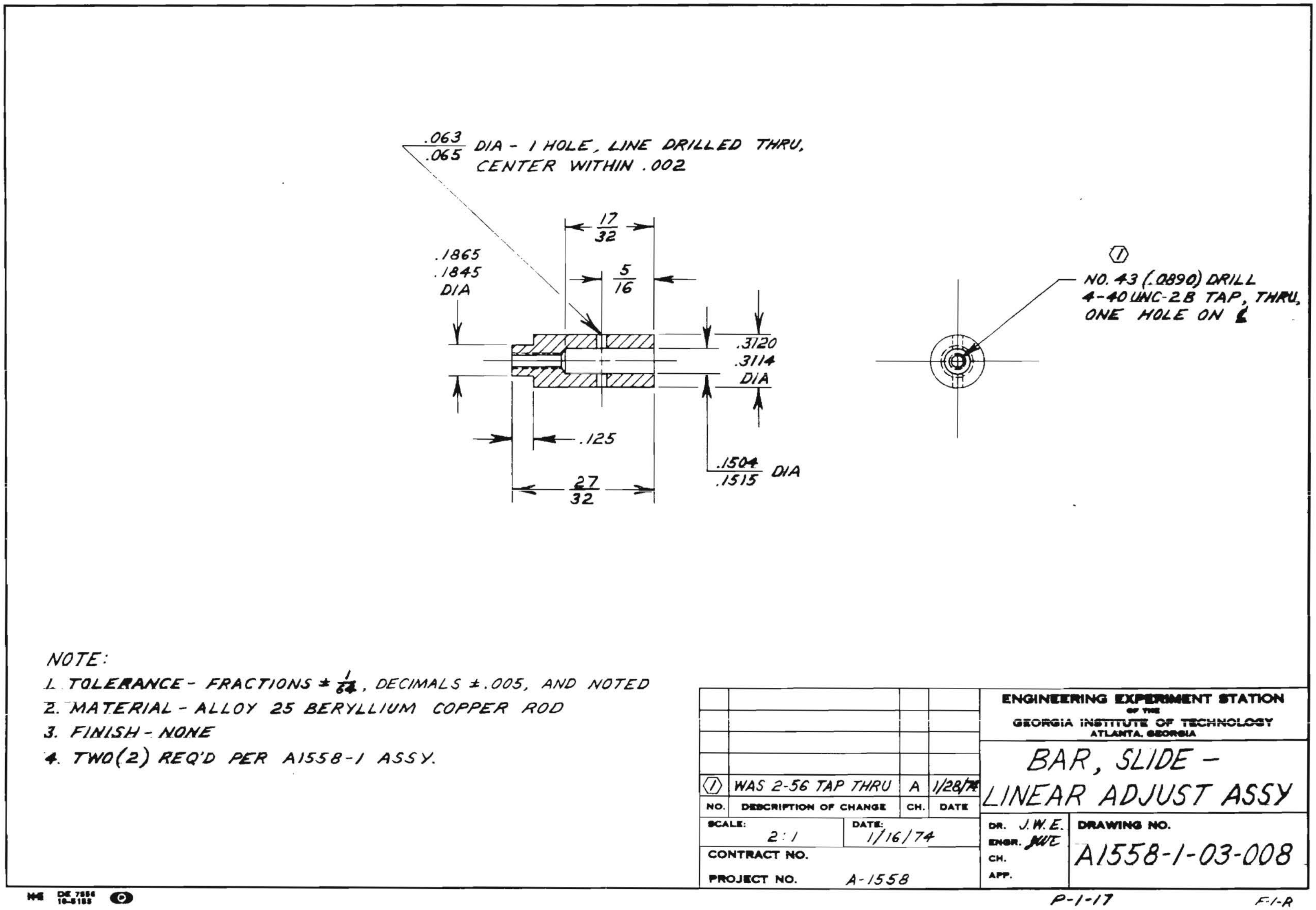


Fig. A23. Bar, slide-linear adjustment.

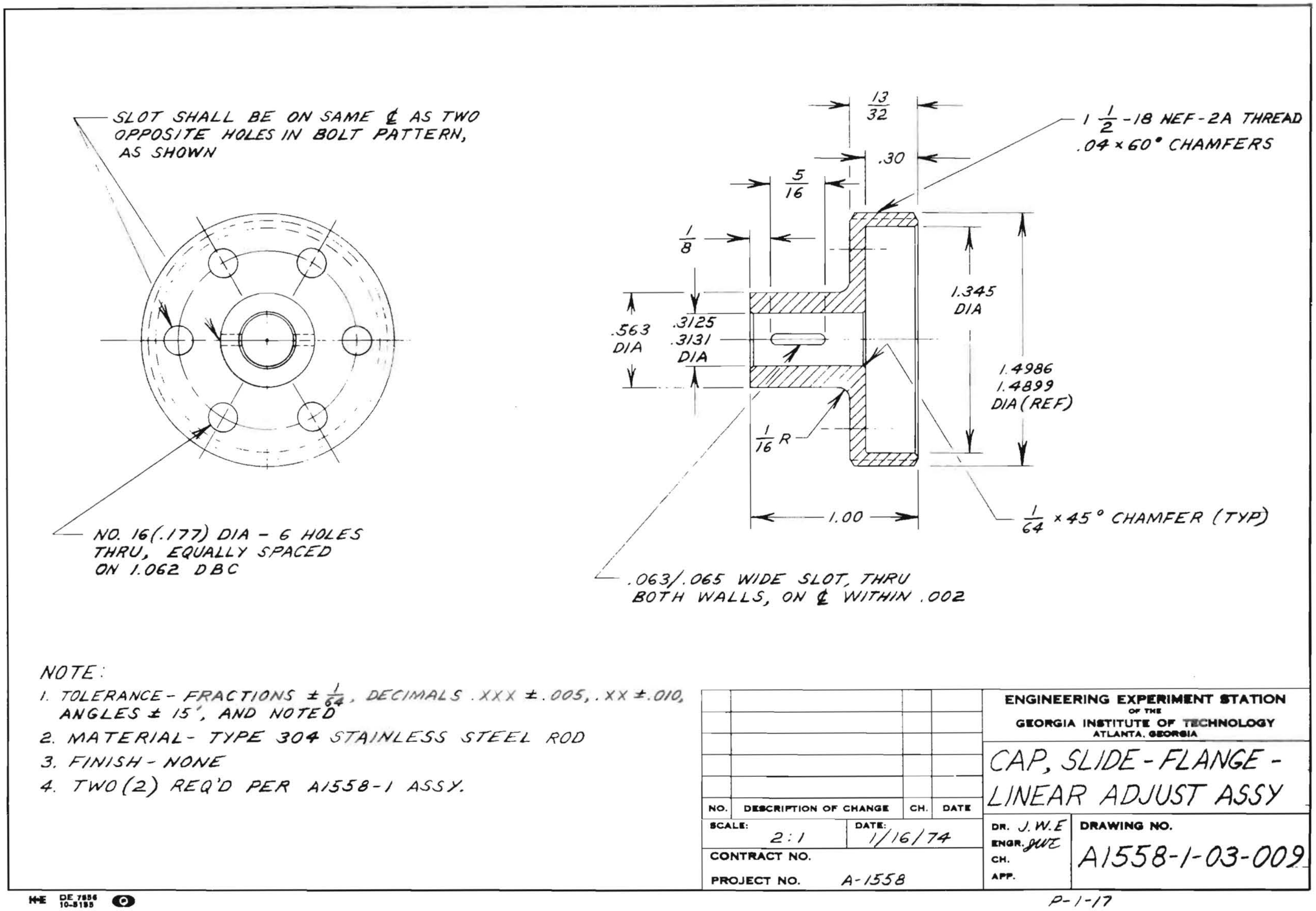


Fig. A24. Cap, slide flange-linear adjustment.

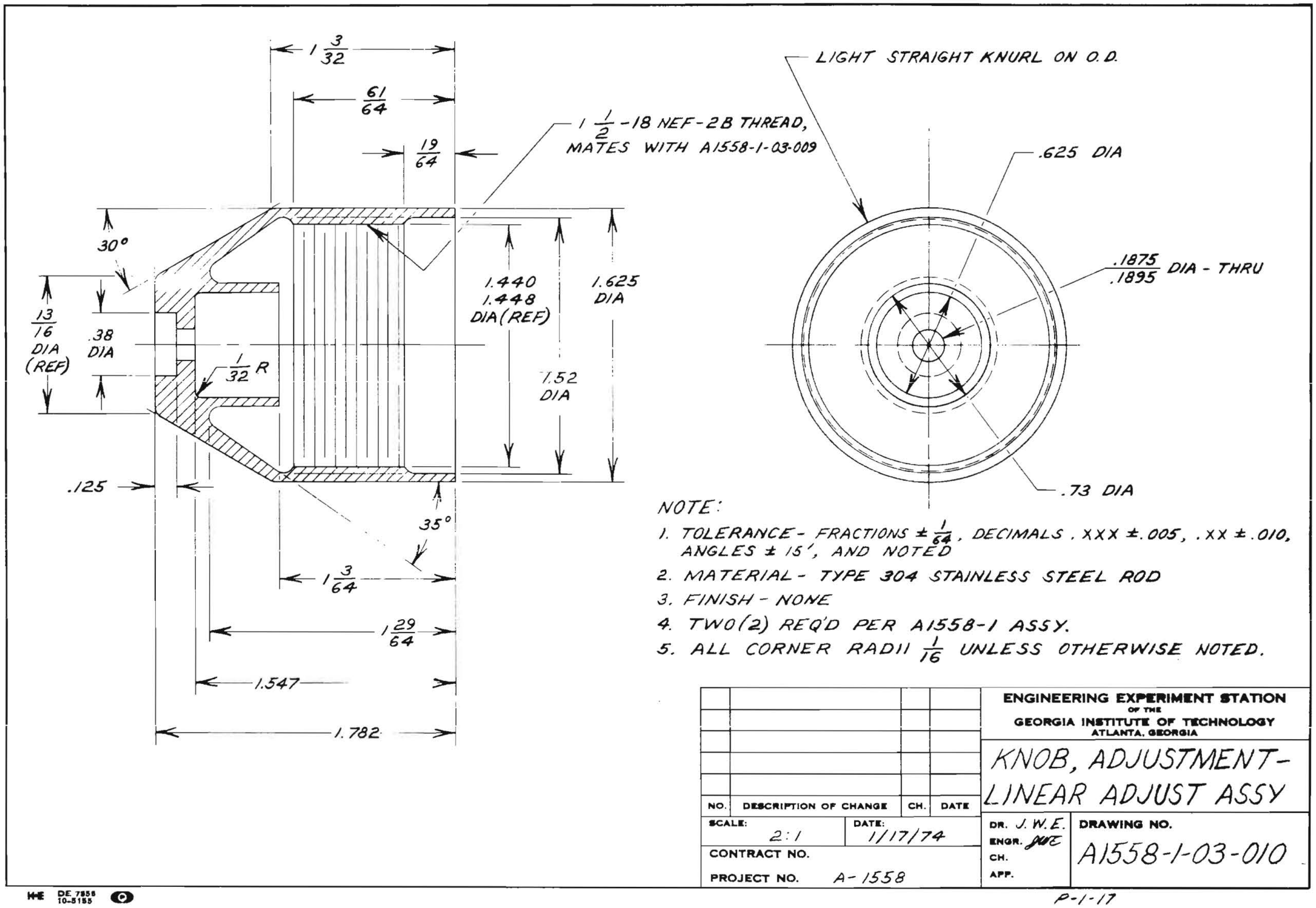
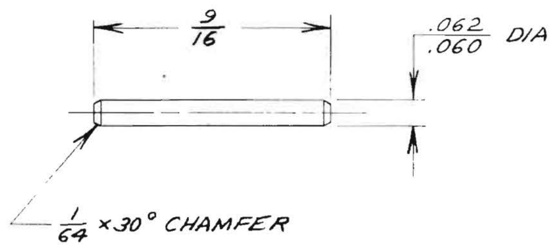


Fig. A25. Knob, adjustment-linear adjustment.



NOTE:
1. TOLERANCE - FRACTIONS ± 1/64, ANGLES ± 1° ¢ NOTED
2. MATERIAL - TYPE 304 STAINLESS STEEL ROD
3. FINISH - NONE
4. TWO (2) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

PIN, TORQUE REACT-LINEAR ADJUST ASSY

SCALE: 4:1
DATE: 1/17/74
CONTRACT NO.
PROJECT NO. A-1558
DR. JWE
ENGR. JWE
CH.
APP.
DRAWING NO. A1558-1-03-011

H-E DE 7556 10-8155

P-1-17

Fig. A26. Pin, torque react-linear adjustment.

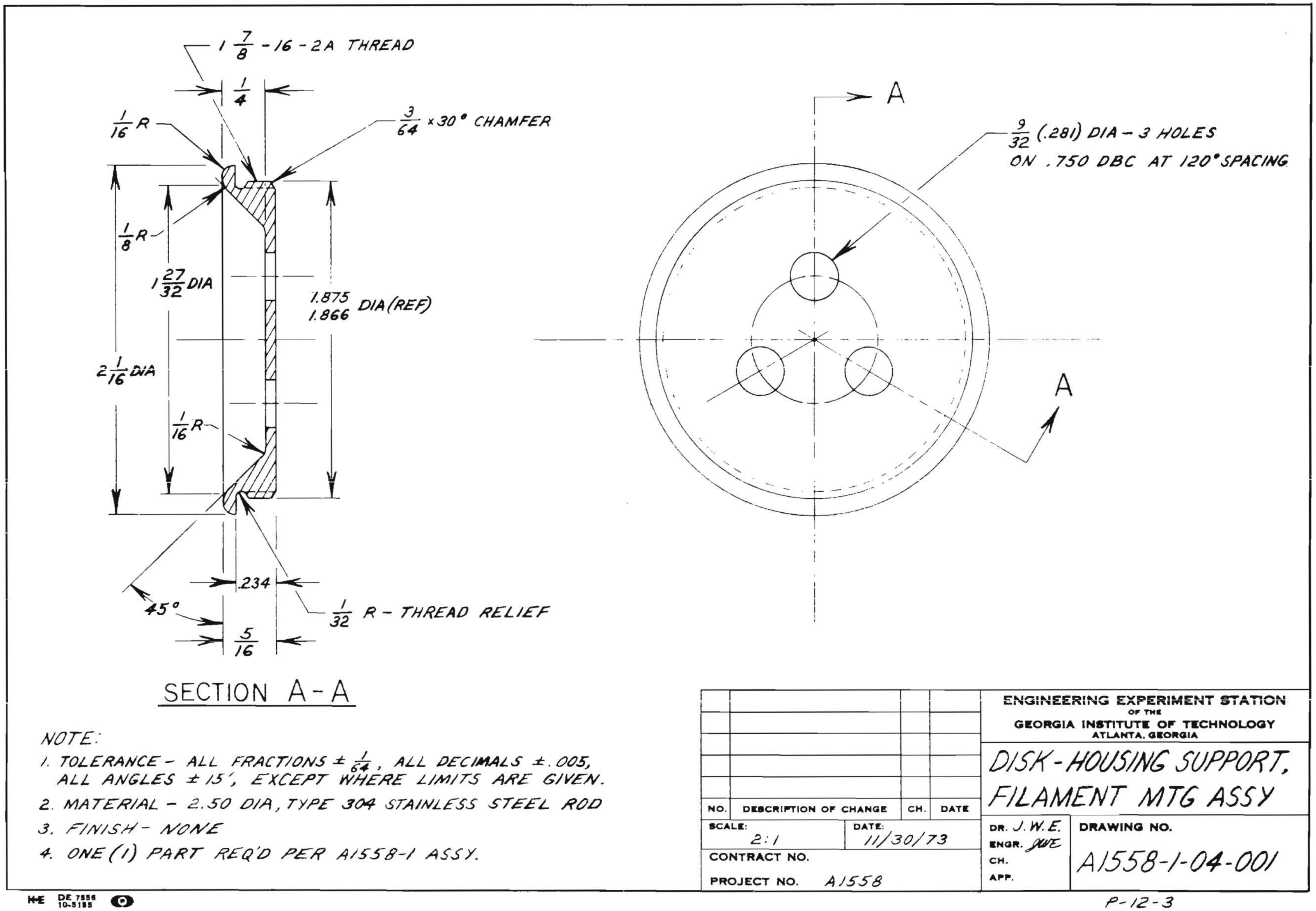
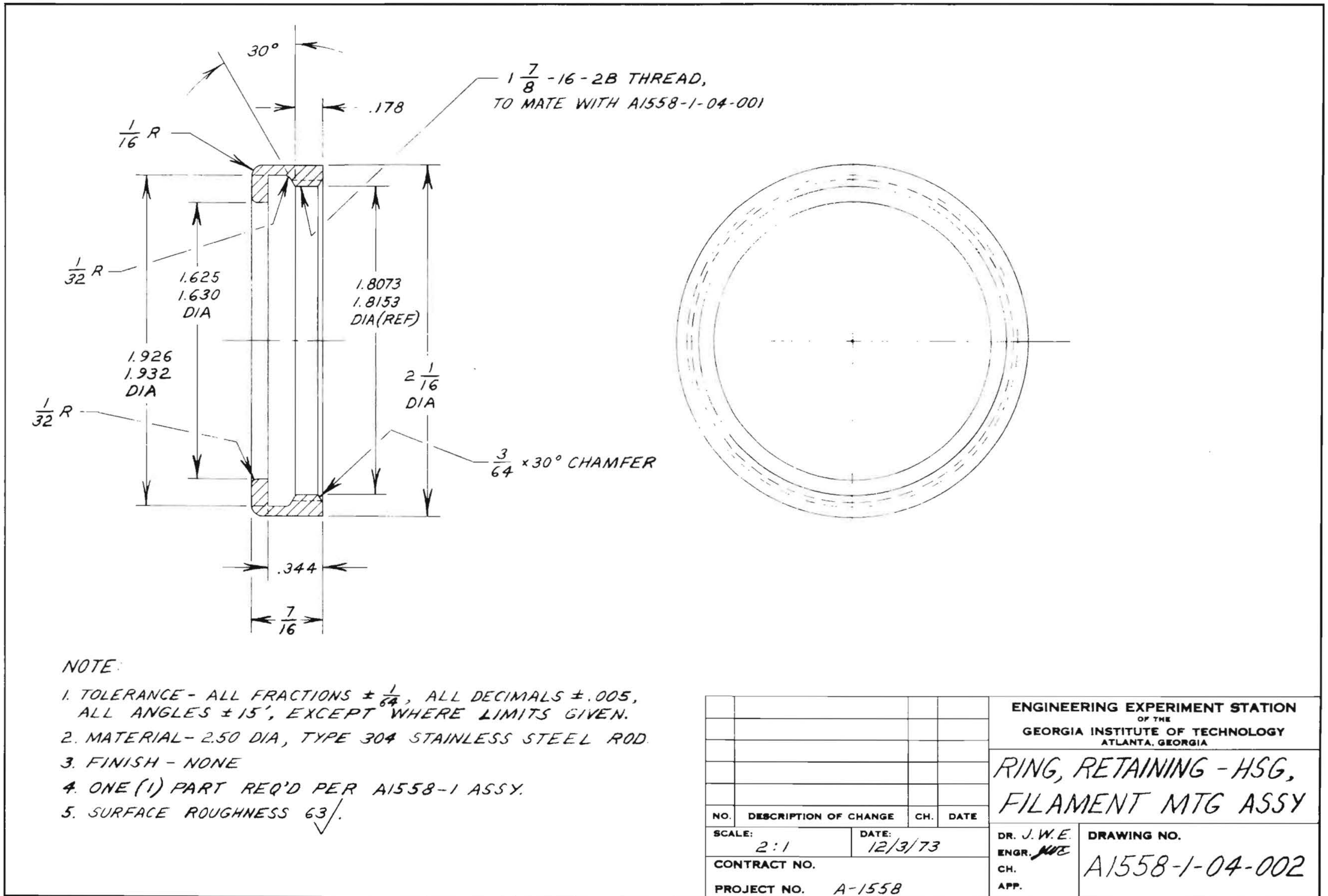


Fig. A27. Disc, housing support-filament mounting assembly.



K+E DE 7556 10-5155

P-12-3

Fig. A28. Ring, retaining-filament mounting assembly.

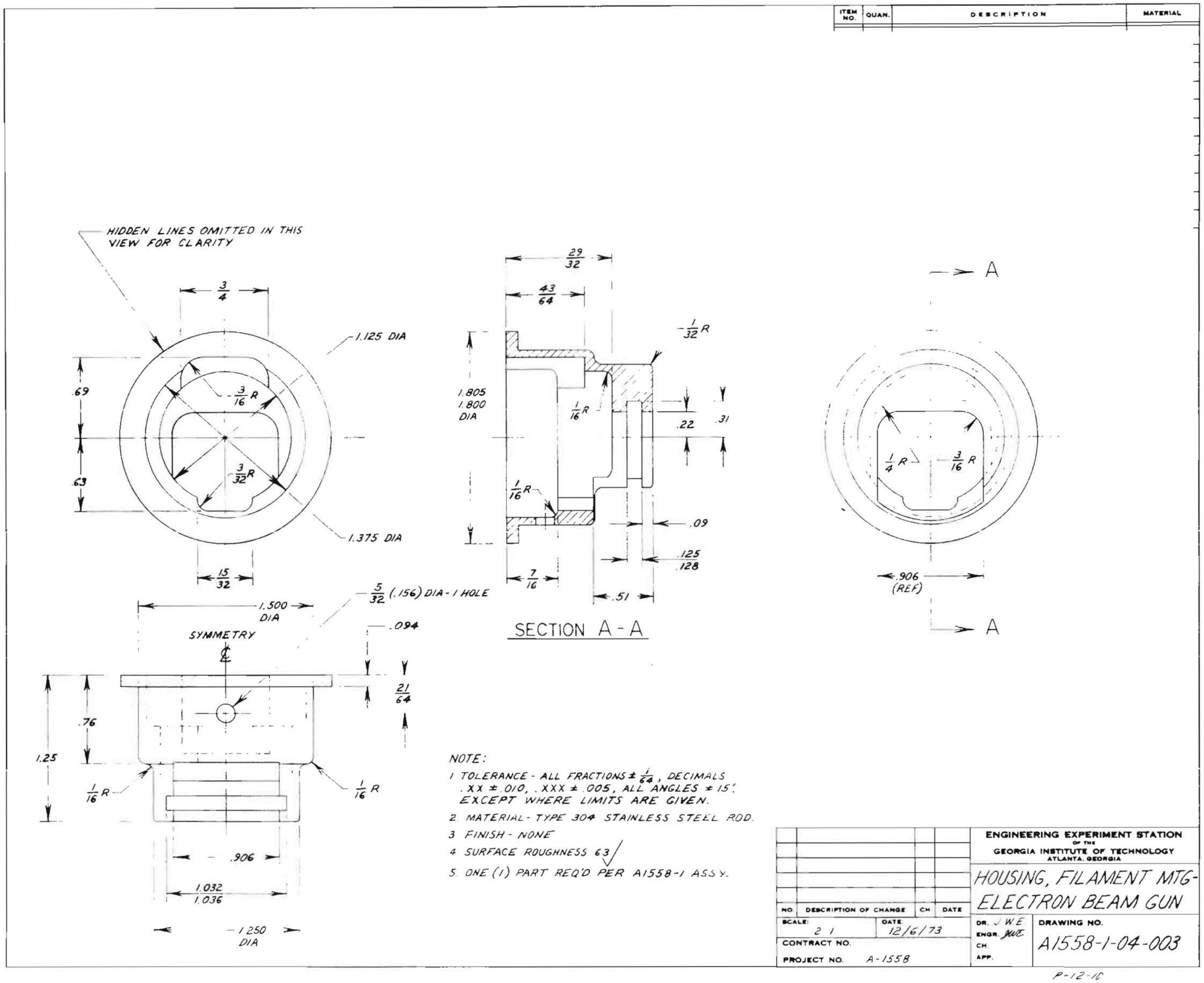
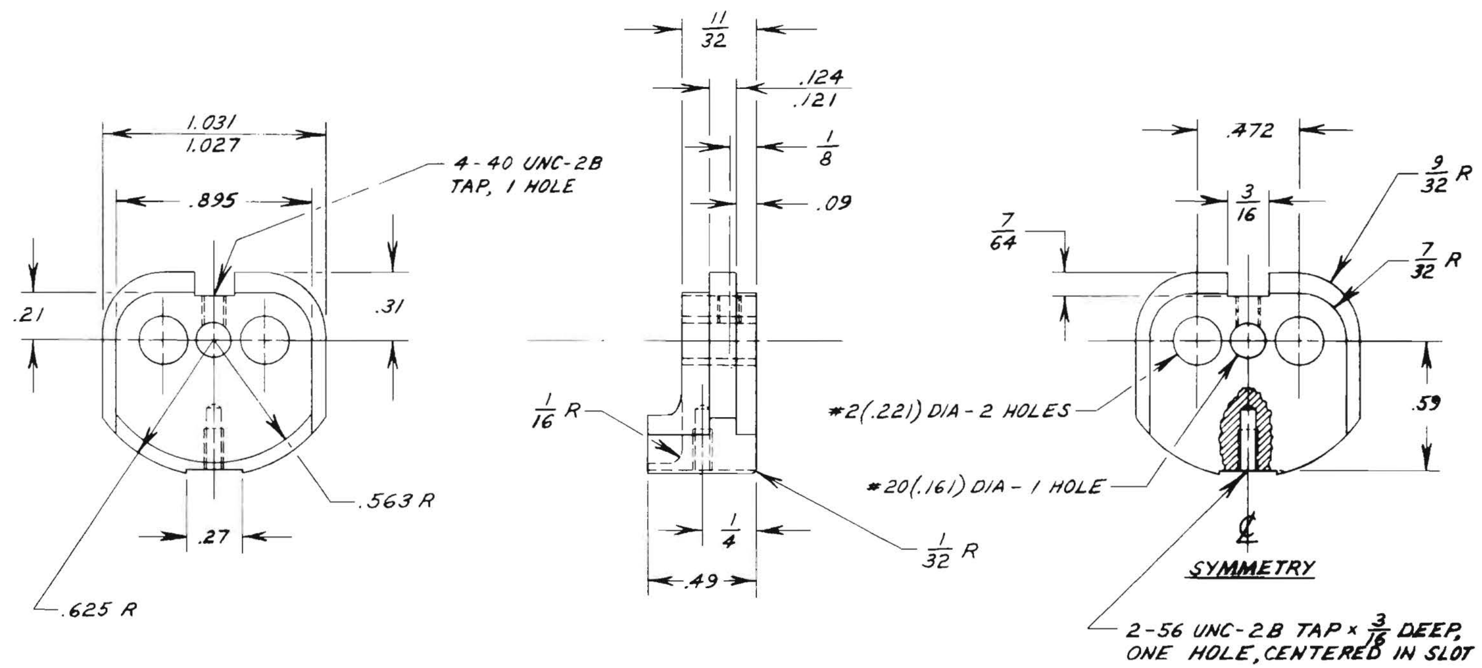


Fig. A29. Housing-filament mounting assembly.



NOTE:

1. TOLERANCE - ALL FRACTIONS ± 1/64, DECIMALS .XXX ±.005, .XX ±.010, ANGLES ±15′, EXCEPT WHERE LIMITS GIVEN.
2. MATERIAL - TYPE 304 STAINLESS STEEL.
3. FINISH - NONE.
4. SURFACE ROUGHNESS 63√
5. ONE (1) PART REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: 2:1 DATE: 12/10/73

CONTRACT NO.

PROJECT NO. A1558

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

ADAPTER, PLUG-IN-FILAMENT MTG HOUSING

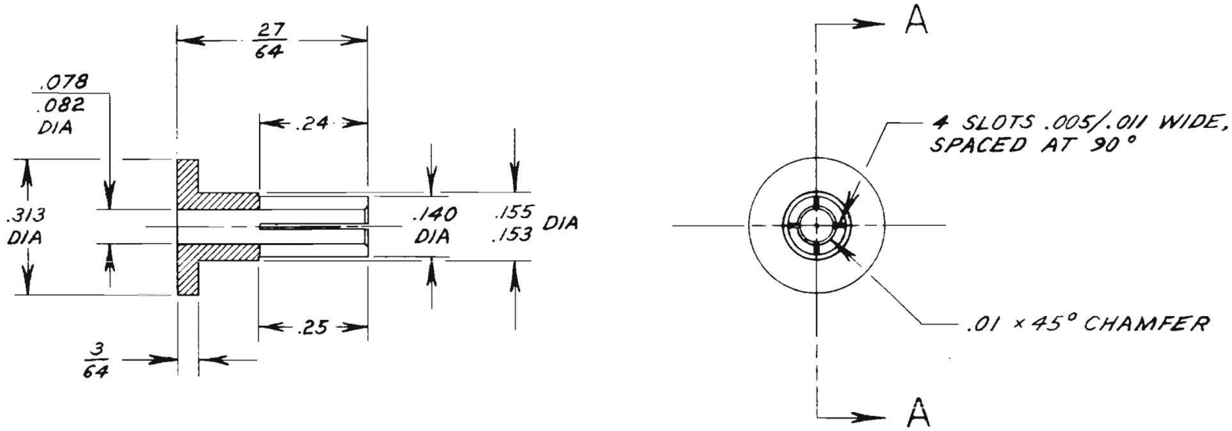
DR. J.W.E. ENGR. JWE CH. APP.

DRAWING NO. A1558-1-04-004

H-E DE 7556 10-8155

P-12-10

Fig. A30. Adapter, plug-in-filament mounting assembly.



SECTION A - A

NOTE:

1. ALL FRACTIONS ± 1/64, DECIMALS .XXX ± .005, .XX ± .010, ANGLES ± 15′, EXCEPT WHERE LIMITS ARE GIVEN.
2. MATERIAL - ALLOY 25 BERYLLIUM COPPER ROD, .375 DIA.
3. FINISH - NONE
4. TWO (2) PARTS REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: 4:1 DATE: 12/11/73

CONTRACT NO.

PROJECT NO. A-1558

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

BUSHING, CONTACT-FILAMENT MTG HOUSING

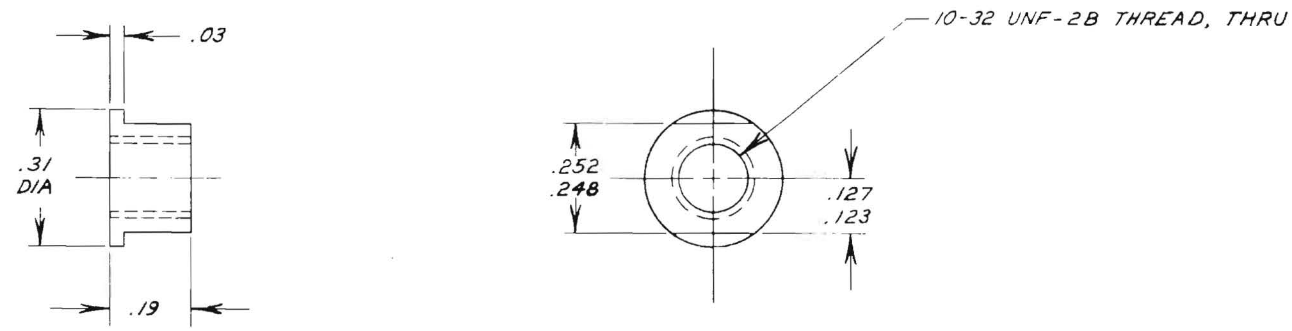
DR. J. W. E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-04-005

K+E DE 7856 10-5155

P-12-12

Fig. A31. Assembly.



NOTE:

1. TOLERANCE - .XX ±.010, EXCEPT WHERE LIMITS GIVEN.
2. MATERIAL - ALLOY 25 BERYLLIUM COPPER ROD, .375 DIA.
3. FINISH - NONE
4. THREE (3) PARTS REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

NUT, INSULATOR STUD-FILAMENT MTG HOUSING

SCALE: 4:1
DATE: 12/11/73
CONTRACT NO.
PROJECT NO. A-1558

DR. J. W. E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-04-006

P-12-12

Fig. A32. Nut, insulator stud-filament mounting assembly.

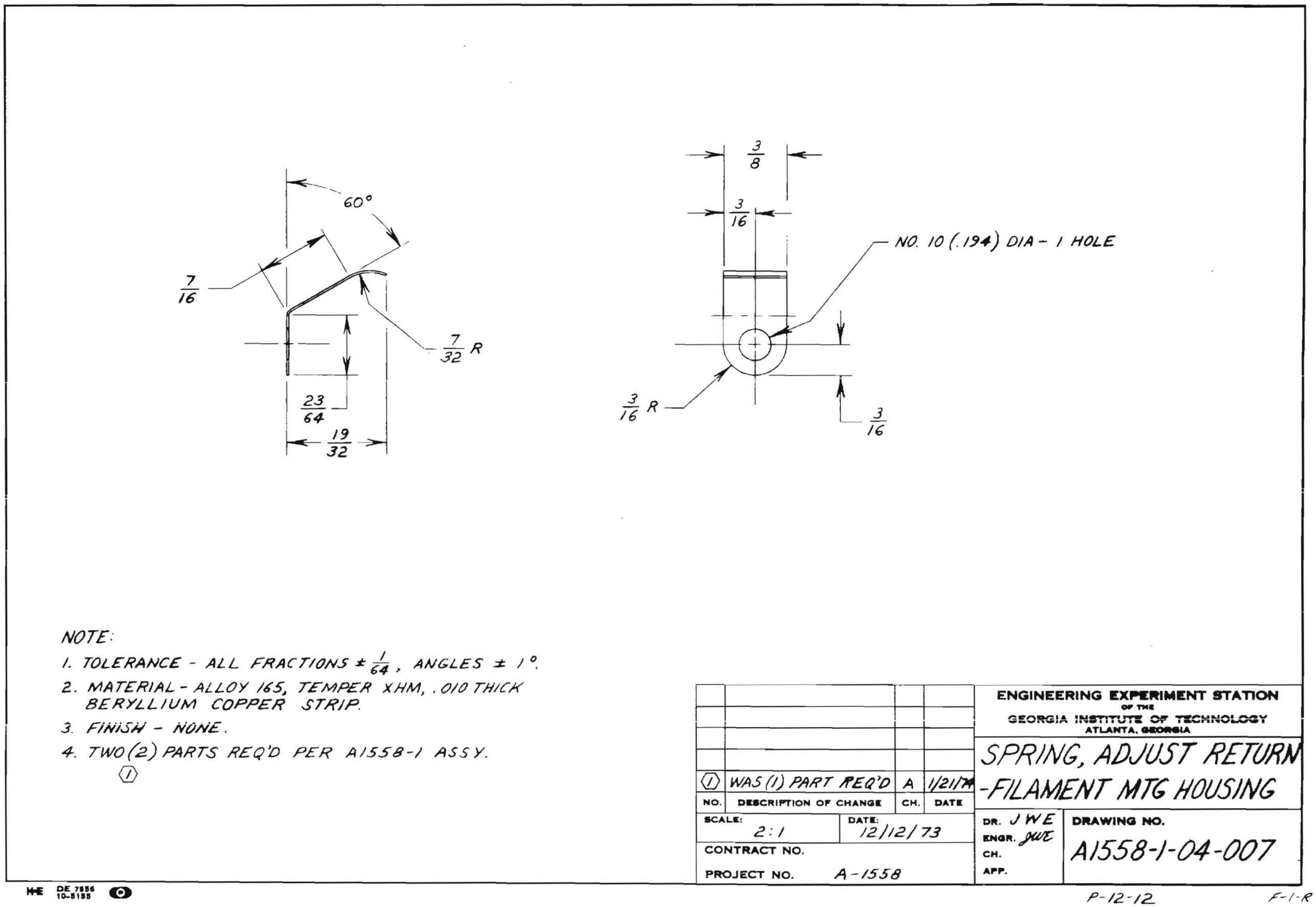


Fig. A33. Spring, adjust return-filament mounting assembly.

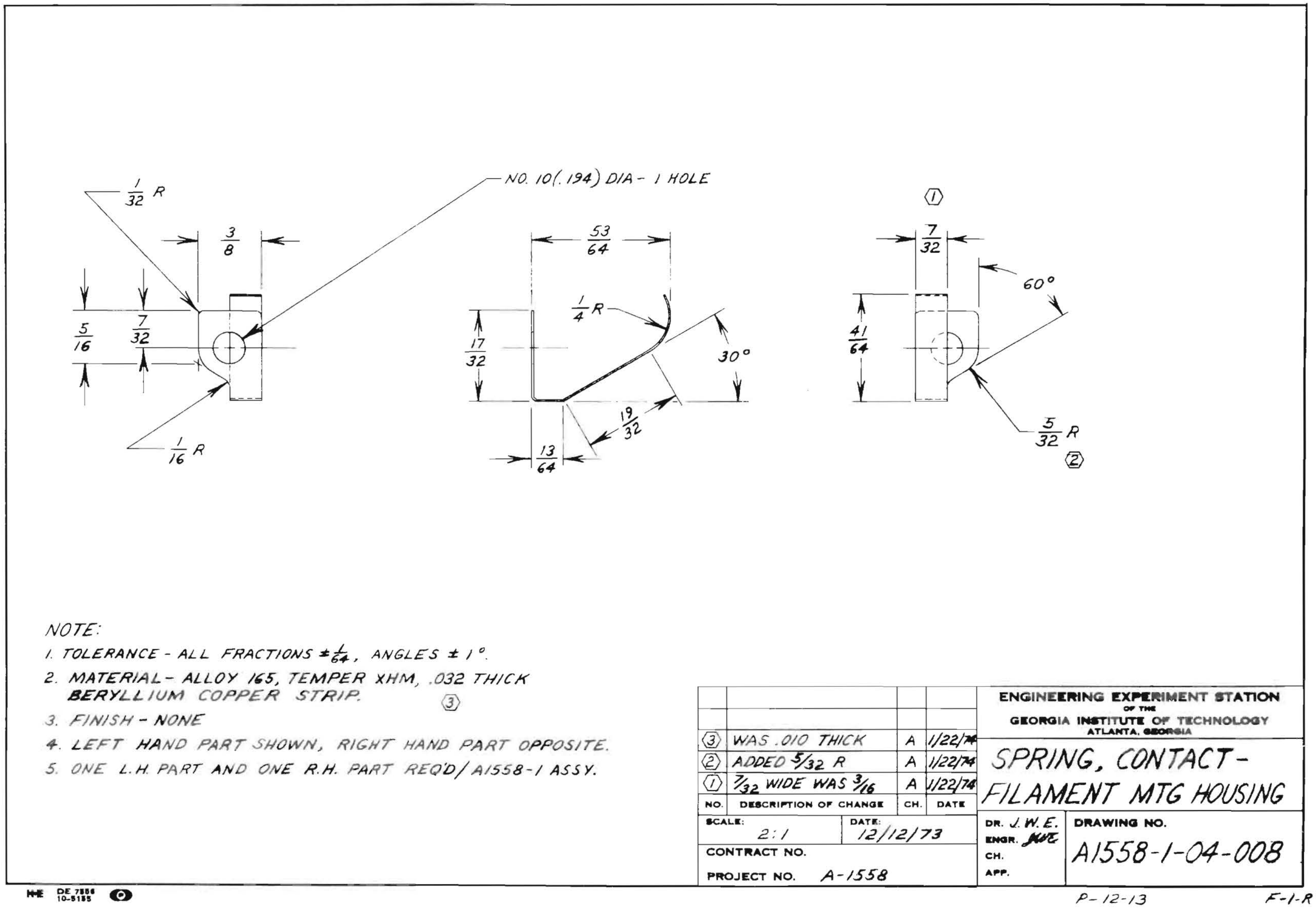
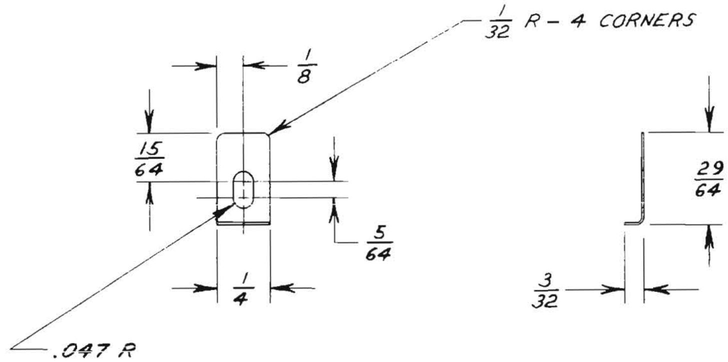


Fig. A34. Spring, contact-filament mounting assembly.



NOTE:

1. TOLERANCE – ALL FRACTIONS ± 1/64 , DECIMALS ± .005.
2. MATERIAL – ALLOY 165, TEMPER XHM, .032 THICK BERYLLIUM COPPER STRIP. (1)
3. FINISH – NONE
4. ONE (1) PART REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE
1	WAS .010 THICK	A	1/22/74

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

CLIP, RETAINER-ADAPTER, FILAMENT MTG HOUSING

SCALE: 2:1 DATE: 12/13/73

CONTRACT NO.

PROJECT NO. A-1558

DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-04-009

H-E DE 7556 10-8155

P-12-13 F-1-R

Fig. A35. Clip, retainer-filament mounting assembly.

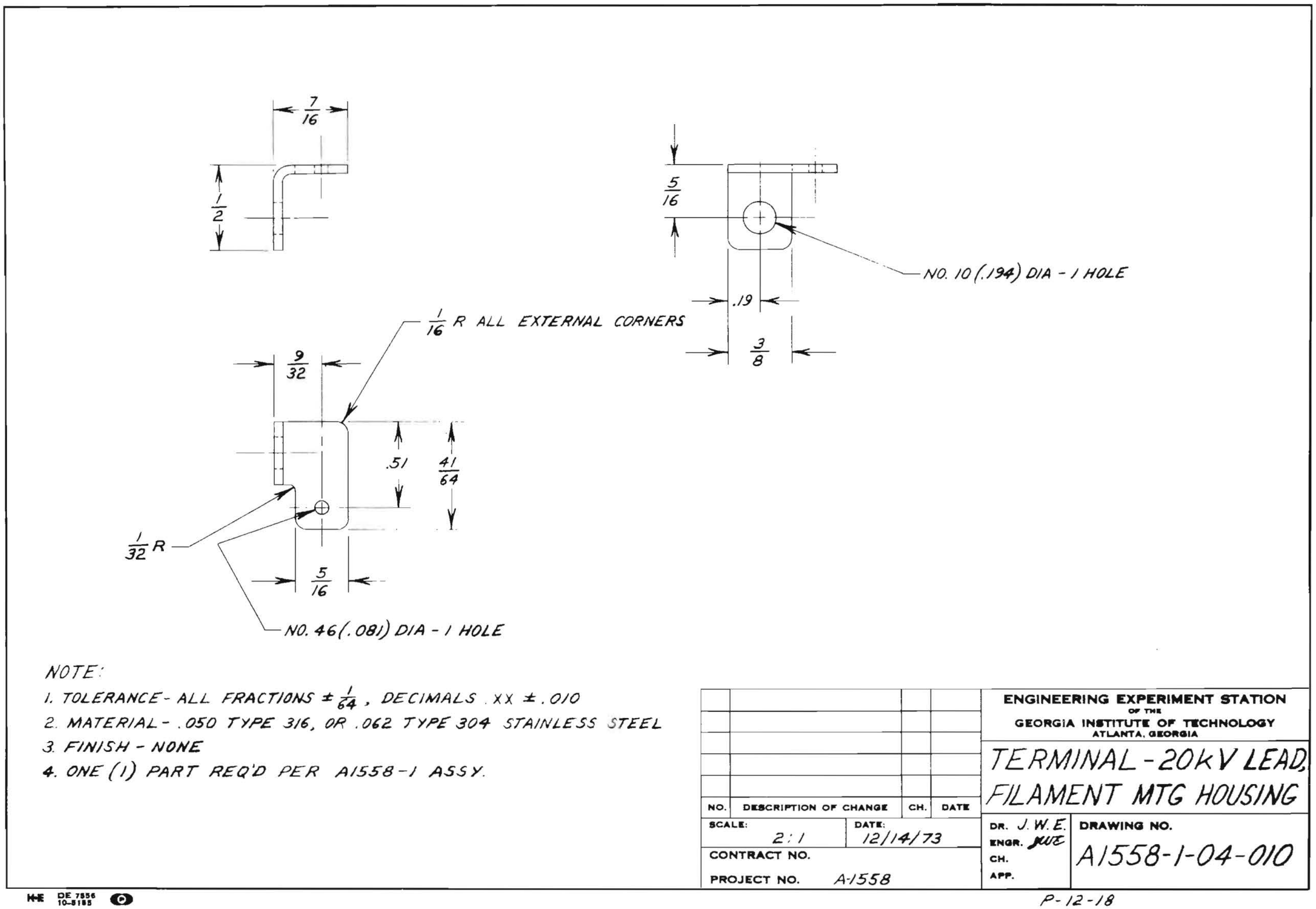


Fig. A36. Terminal, lens high voltage lead, filament mounting assembly.

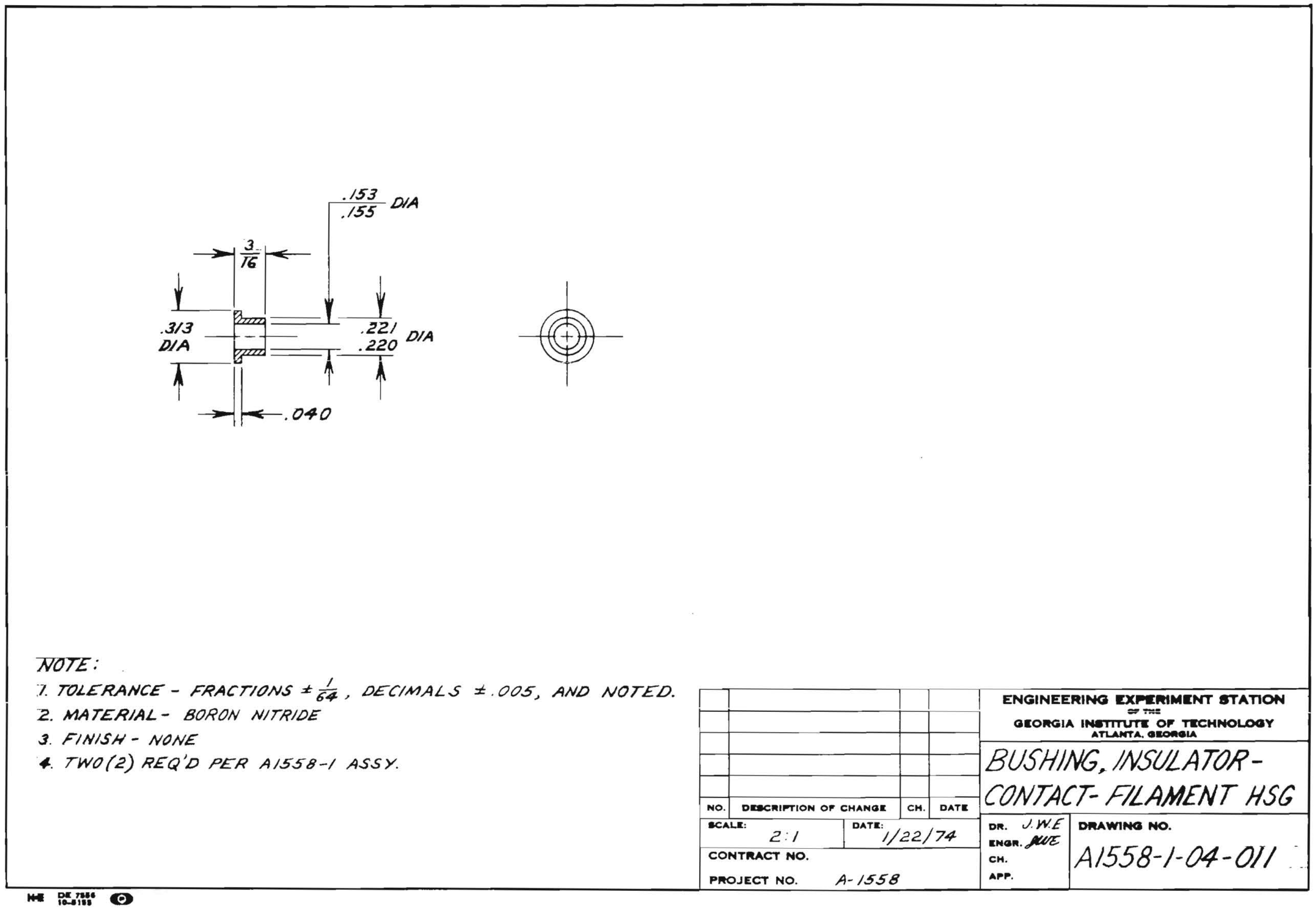


Fig. A37. Insulating bushing-filament mounting assembly.

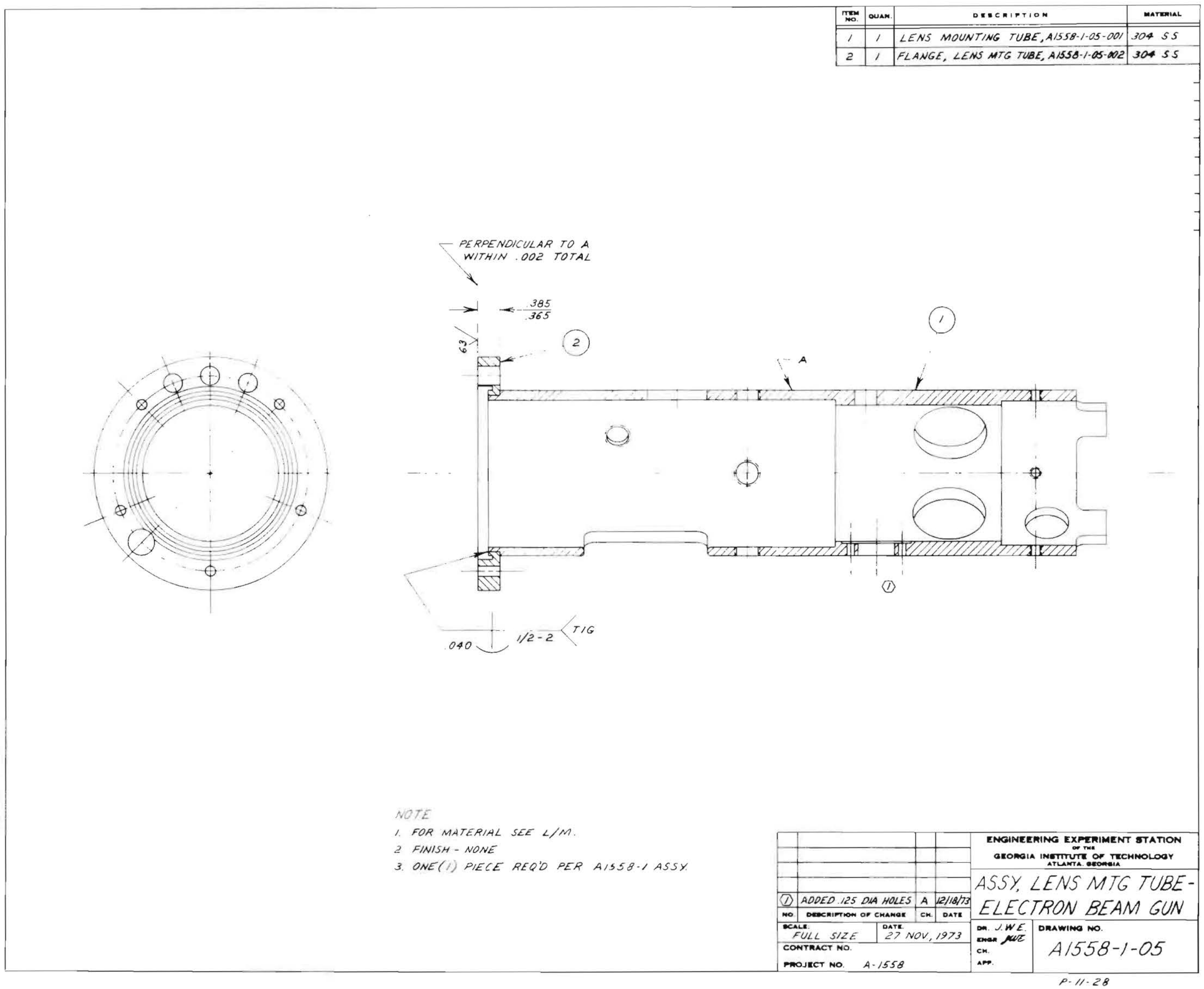


Fig. A38. Assembly-lens mounting tube.

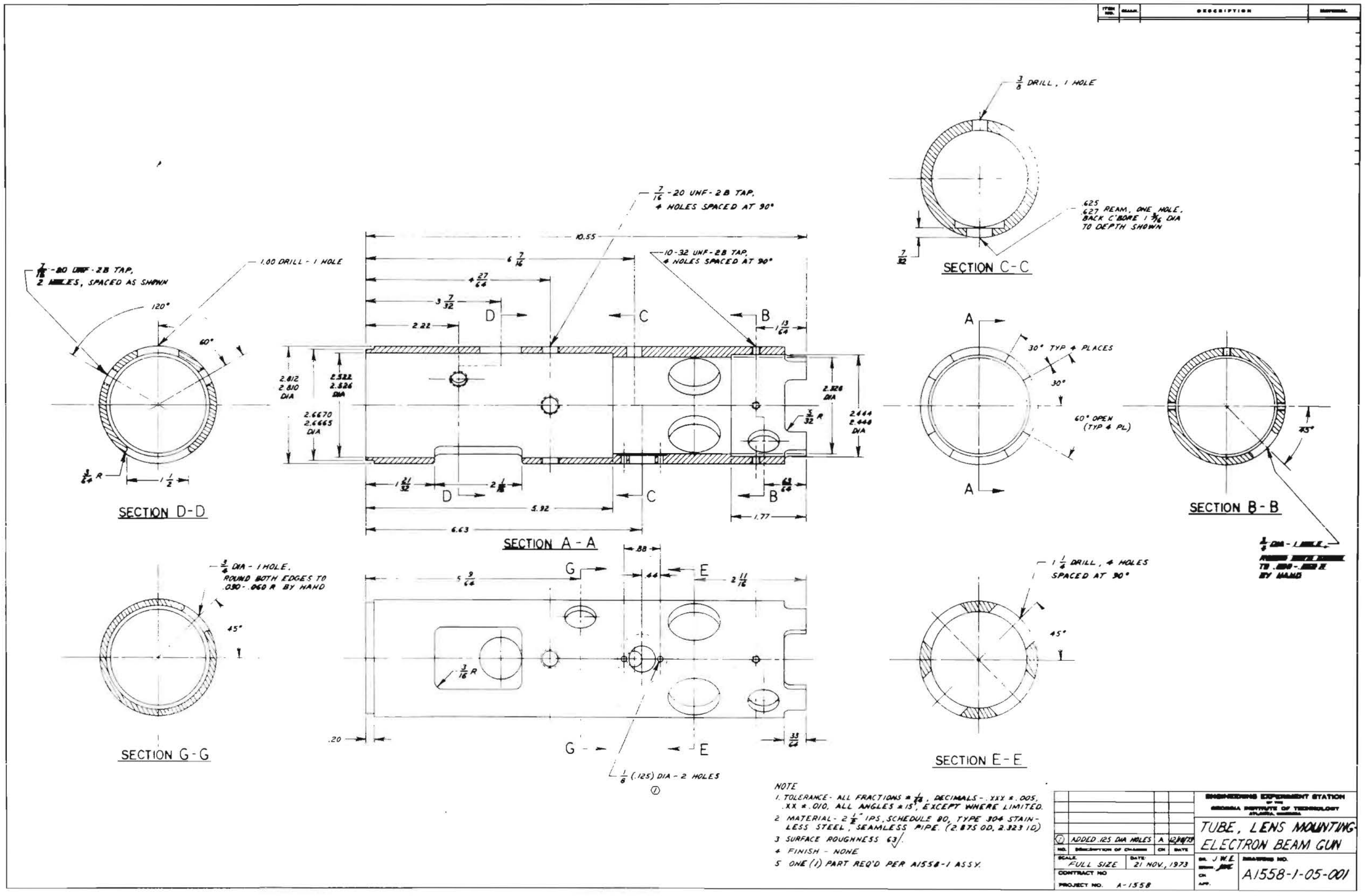


Fig. A39. Tube-lens mounting.

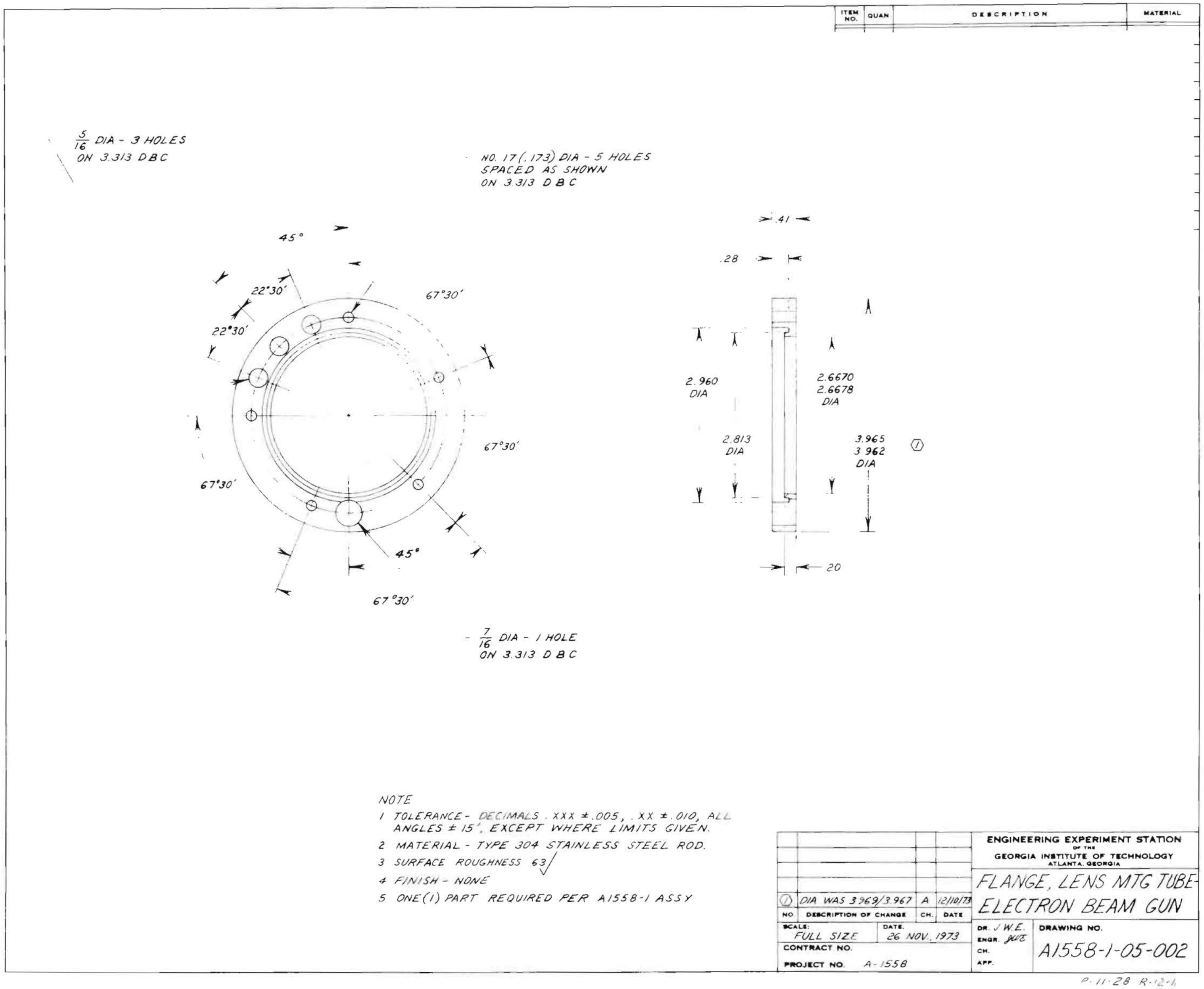


Fig. A40. Flange-lens mounting tube.

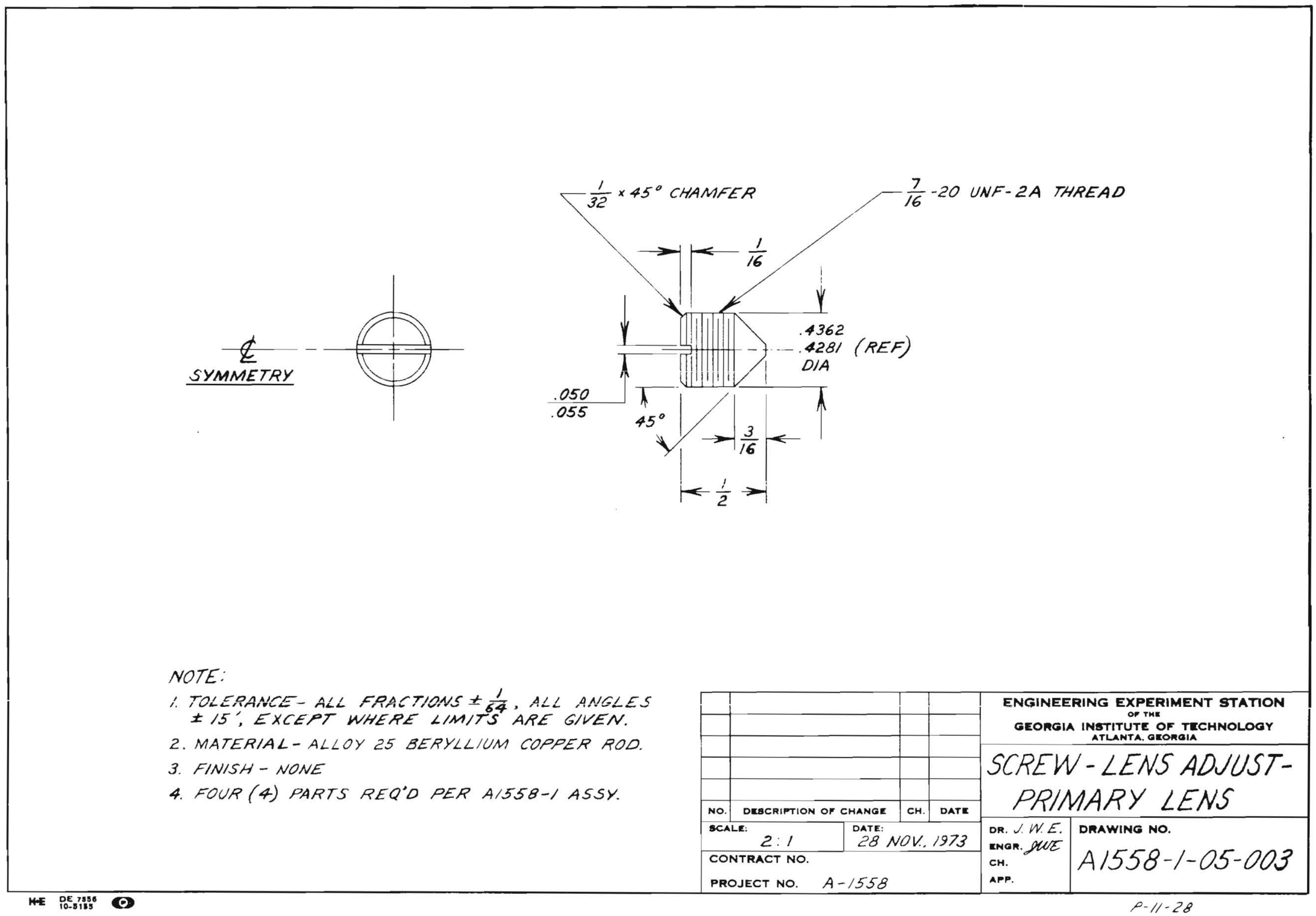
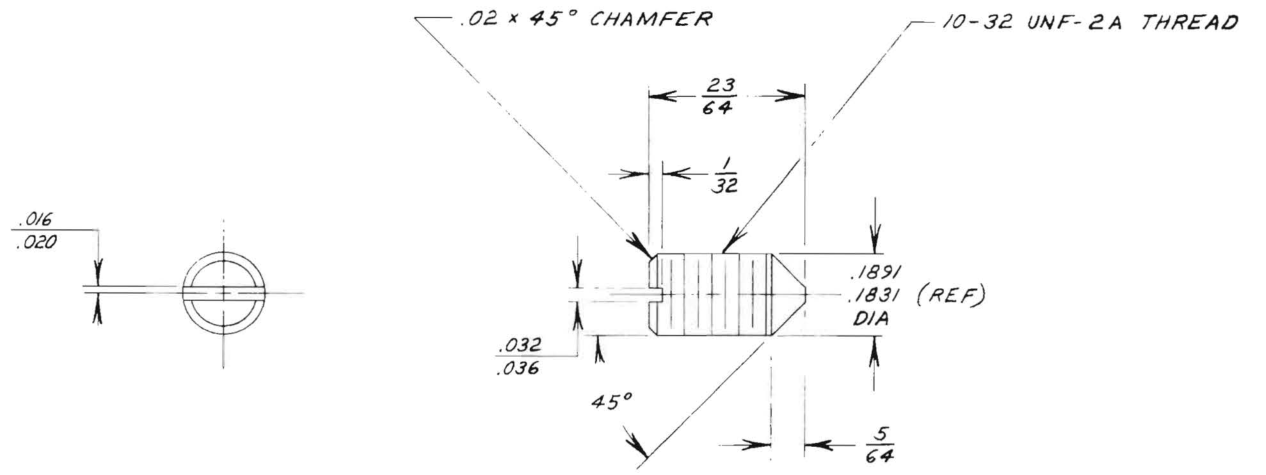


Fig. A41. Screw, lens No. 1 adjuster.

ITEM NO.	QUAN.	DESCRIPTION	MATERIAL



NOTE:

1. TOLERANCE - ALL FRACTIONS ± 1/64, DECIMALS ± .010, ANGLES ± 15', EXCEPT WHERE LIMITS ARE GIVEN.
2. MATERIAL - .250 DIA, ALLOY 25 BERYLLIUM COPPER
3. FINISH - NONE
4. FOUR (4) PARTS REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: 4:1 DATE: 28 NOV, 1973

CONTRACT NO.

PROJECT NO. A-1558

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

SCREW - LENS RETAIN, SECONDARY LENS

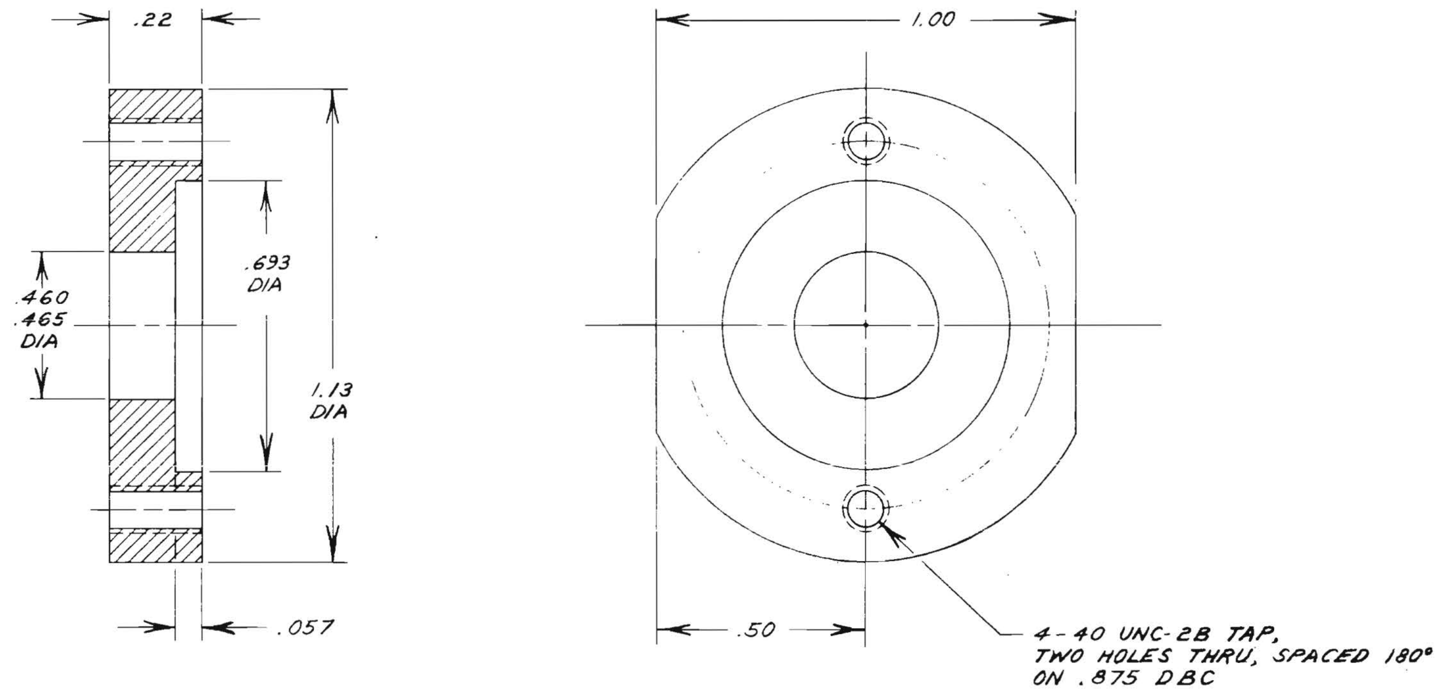
DR. J. W. E.
ENGR.
CH.
APP.

DRAWING NO. A1558-1-05-004

K+E DE-4892 10-5159

P-11-28

Fig. A42. Screw, lens No. 2 adjuster.



NOTE:

1. TOLERANCE - DECIMALS .XXX ± .005, .XX ± .010, ANGLES ± 15'
2. MATERIAL - T.F.E. "TEFLON" 1/4" THICK PLATE
3. FINISH - NONE
4. ONE (1) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

RETAINER, PLUG - MODULATOR, MTG TUBE

SCALE: 4:1 DATE: 1/21/74

CONTRACT NO.

PROJECT NO. A-1558

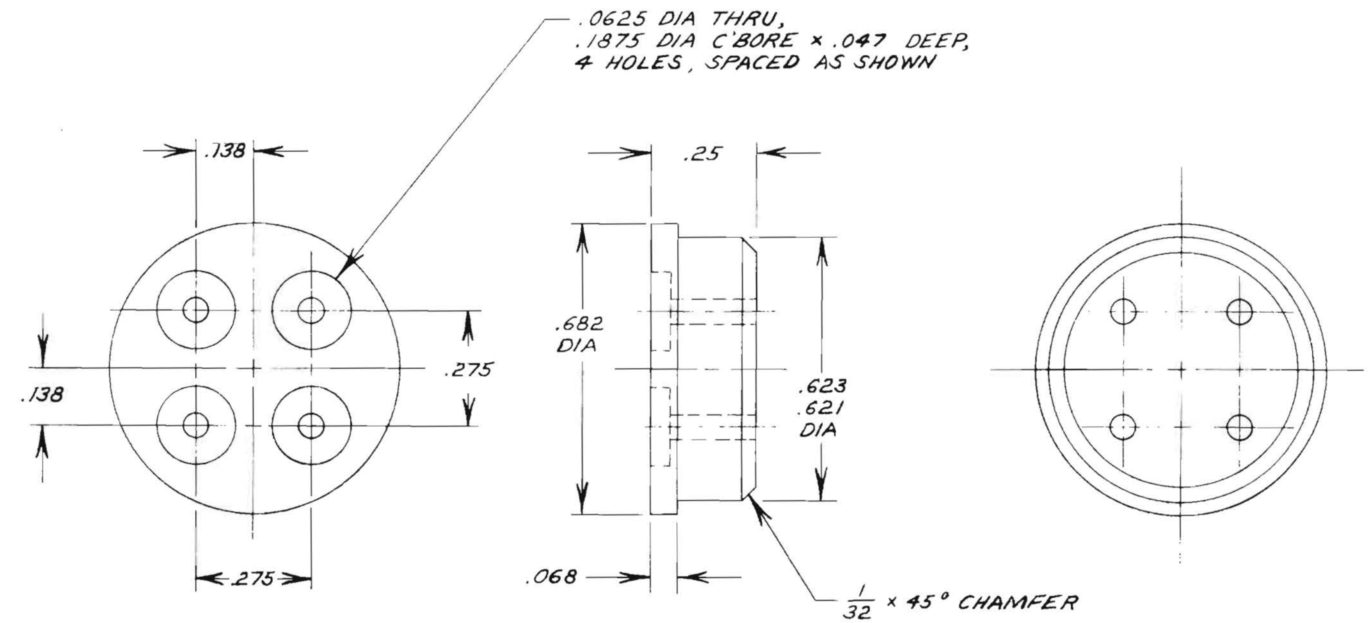
DR. J. W. E ENGR. JWE CH. APP.

DRAWING NO. A1558-1-05-005

H-E DE 7556 10-5185

P-1-21

Fig. A43. Retainer, modulator plug-lens mounting tube.



NOTE:

1. TOLERANCE - FRACTIONS ± 1/64, DECIMALS .XXX ±.005, .XX ±.010, ANGLES ± 1°, ℄ NOTED.
2. MATERIAL - T.F.E. "TEFLON" 1/4" THICK PLATE
3. FINISH - NONE
4. ONE (1) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

PLUG, CONNECTOR - MODULATOR, MTG TUBE

SCALE: 4:1
DATE: 1/21/74
CONTRACT NO.
PROJECT NO. A-1558
DR. J.W.E.
ENGR. JWE
CH.
APP.
DRAWING NO. A1558-1-05-006

H-E DE 7556 10-8185

P-1-21

Fig. A44. Connector, modulator plug-lens mounting tube.

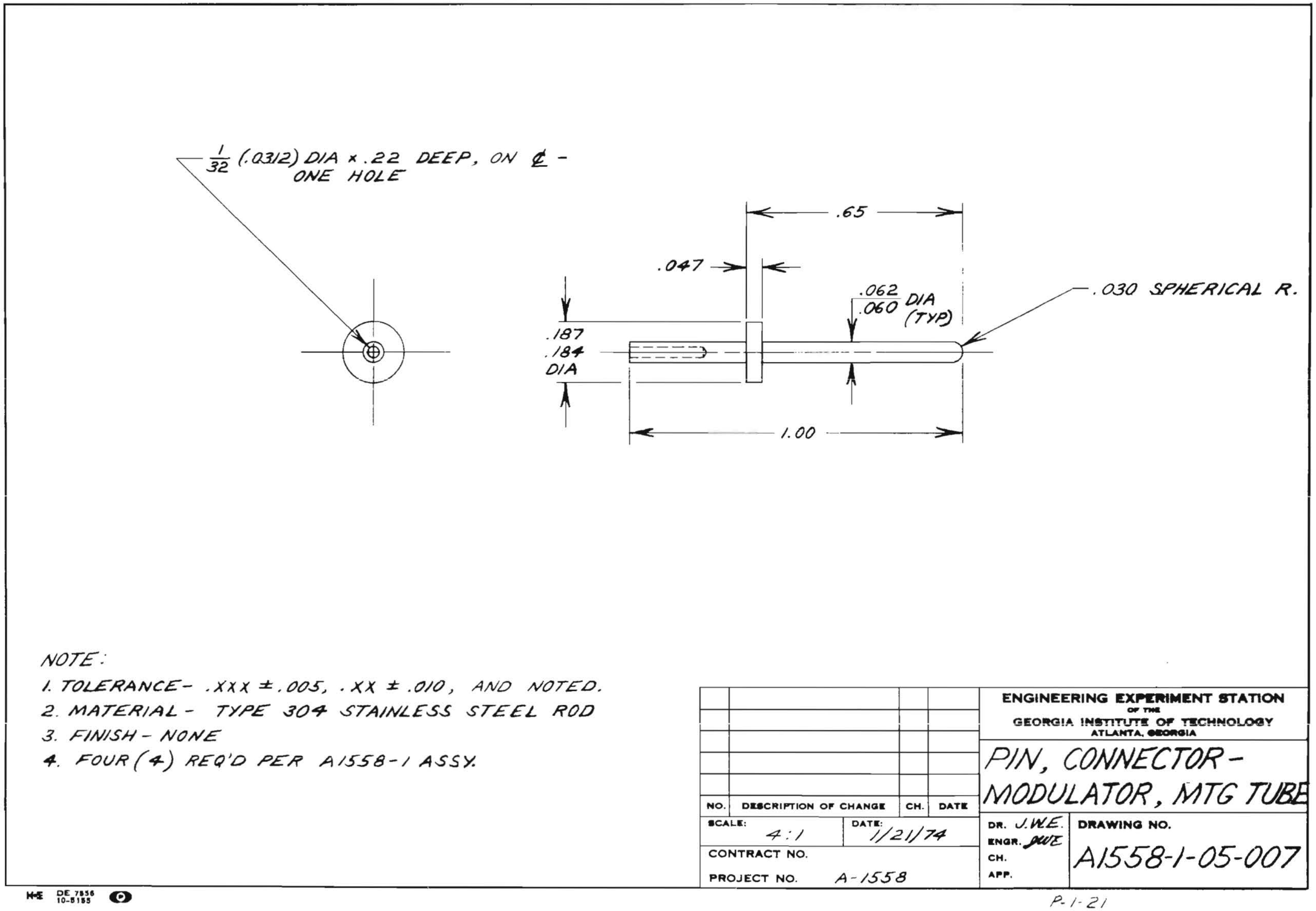


Fig. A45. Pin, modulator plug-lens mounting tube.

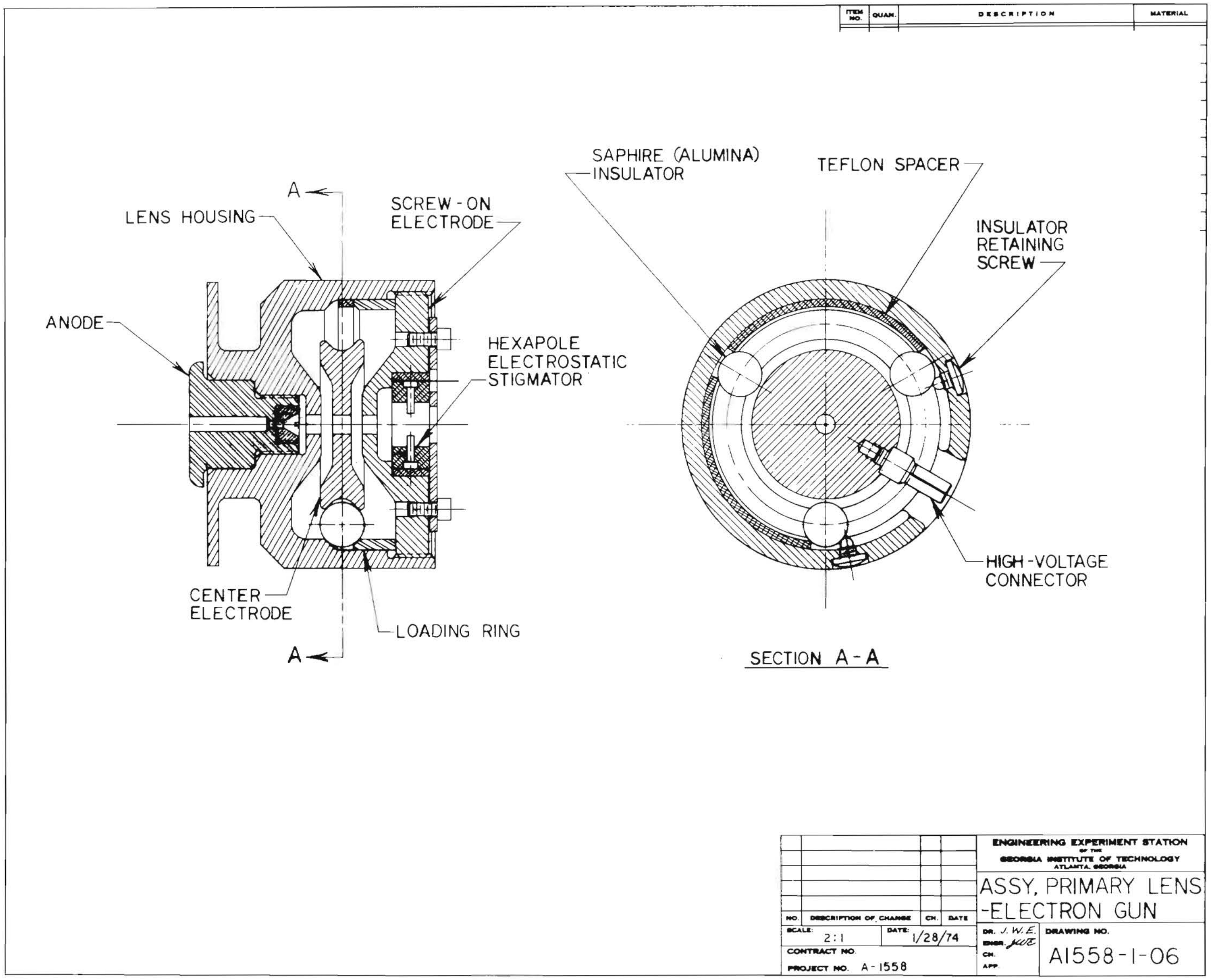
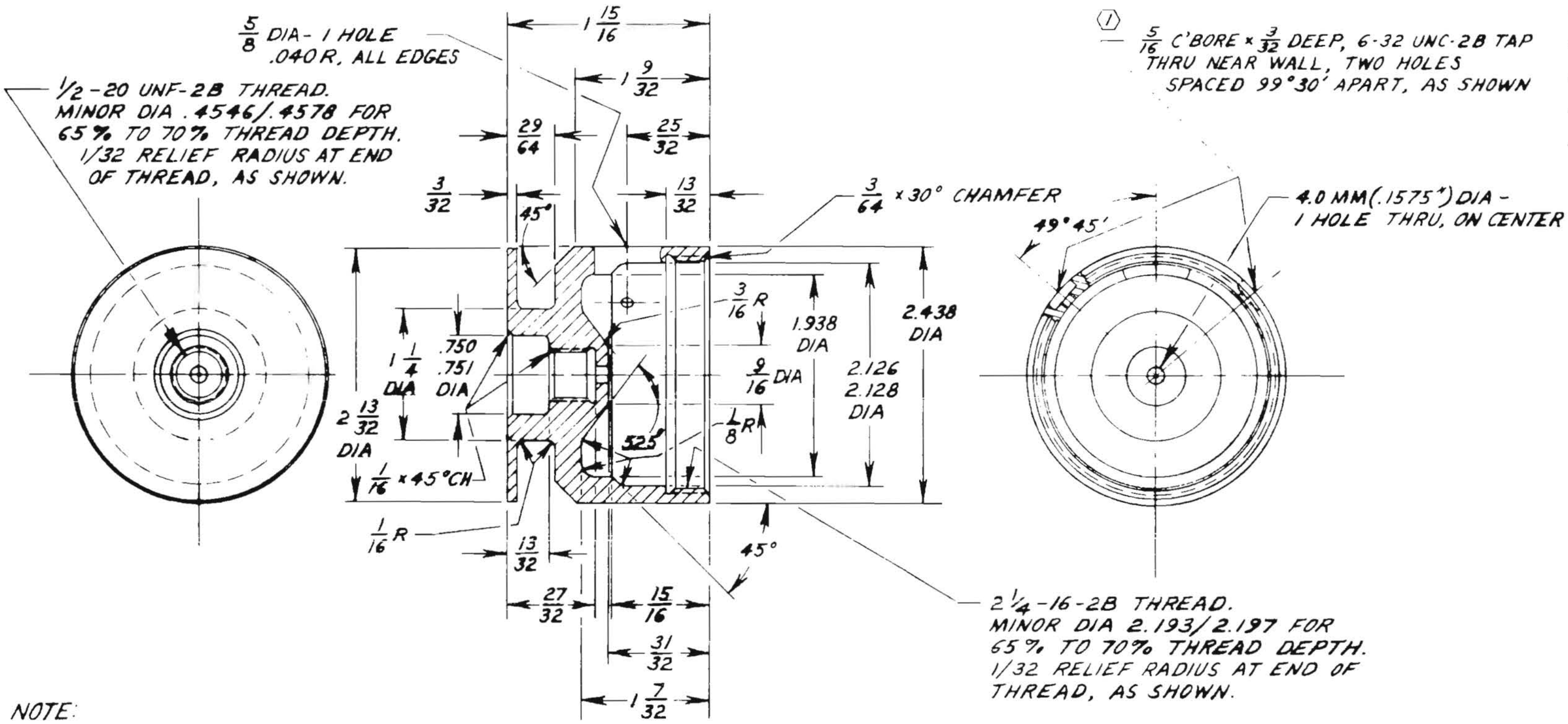


Fig. A46. Assembly-lens No. 1.

ITEM NO.	QUAN.	DESCRIPTION	MATERIAL



NOTE:

1. TOLERANCE - ALL FRACTIONS ± 1/64, ALL DECIMALS ±.005, ALL ANGLES ± 15', EXCEPT WHERE LIMITS ARE GIVEN.
2. MATERIAL - 6AL-4V TITANIUM PER MIL-T-9047-F-COMP 6.
3. SURFACE ROUGHNESS - INTERIOR SURFACES 32√, EXTERIOR 64√.
4. FINISH - NONE.
5. ONE (1) PART REQUIRED PER A1558-1 ASSY.
6. ALL INSIDE CORNER RADII 1/32 UNLESS OTHERWISE SPECIFIED.

NO.	DESCRIPTION OF CHANGE	CH.	DATE
1	ADDED 2 HOLES	A	11/15/73

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

HOUSING - PRIMARY LENS, ELECTRON BEAM GUN

SCALE FULL SIZE	DATE 9 OCT., 1973	DR. J.W.E.	DRAWING NO.
CONTRACT NO		ENGR. JWE	A1558-1-06-001
PROJECT NO A-1558		CH.	
		APP	

K-11-16

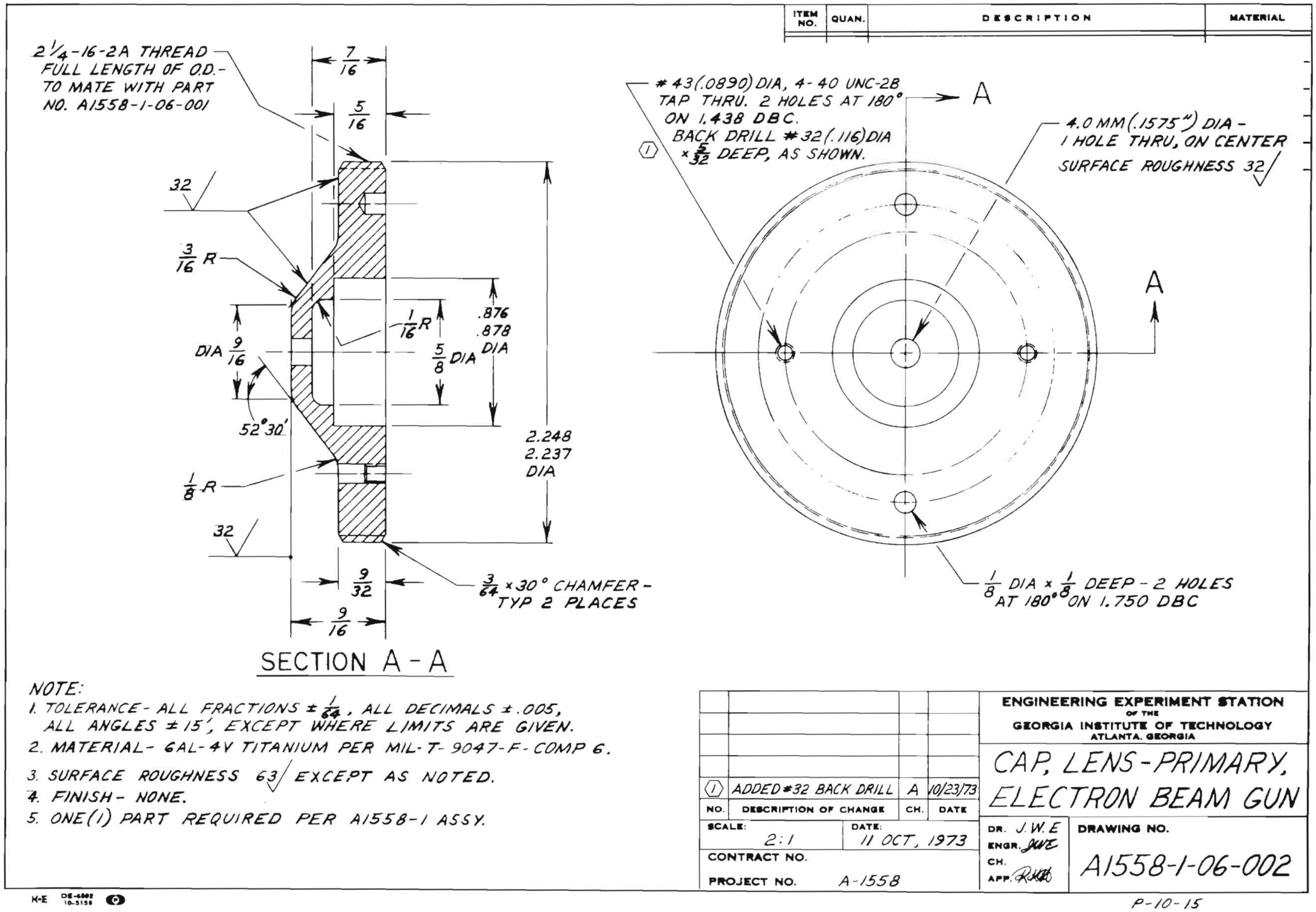


Fig. A48. Cap-lens No. 1.

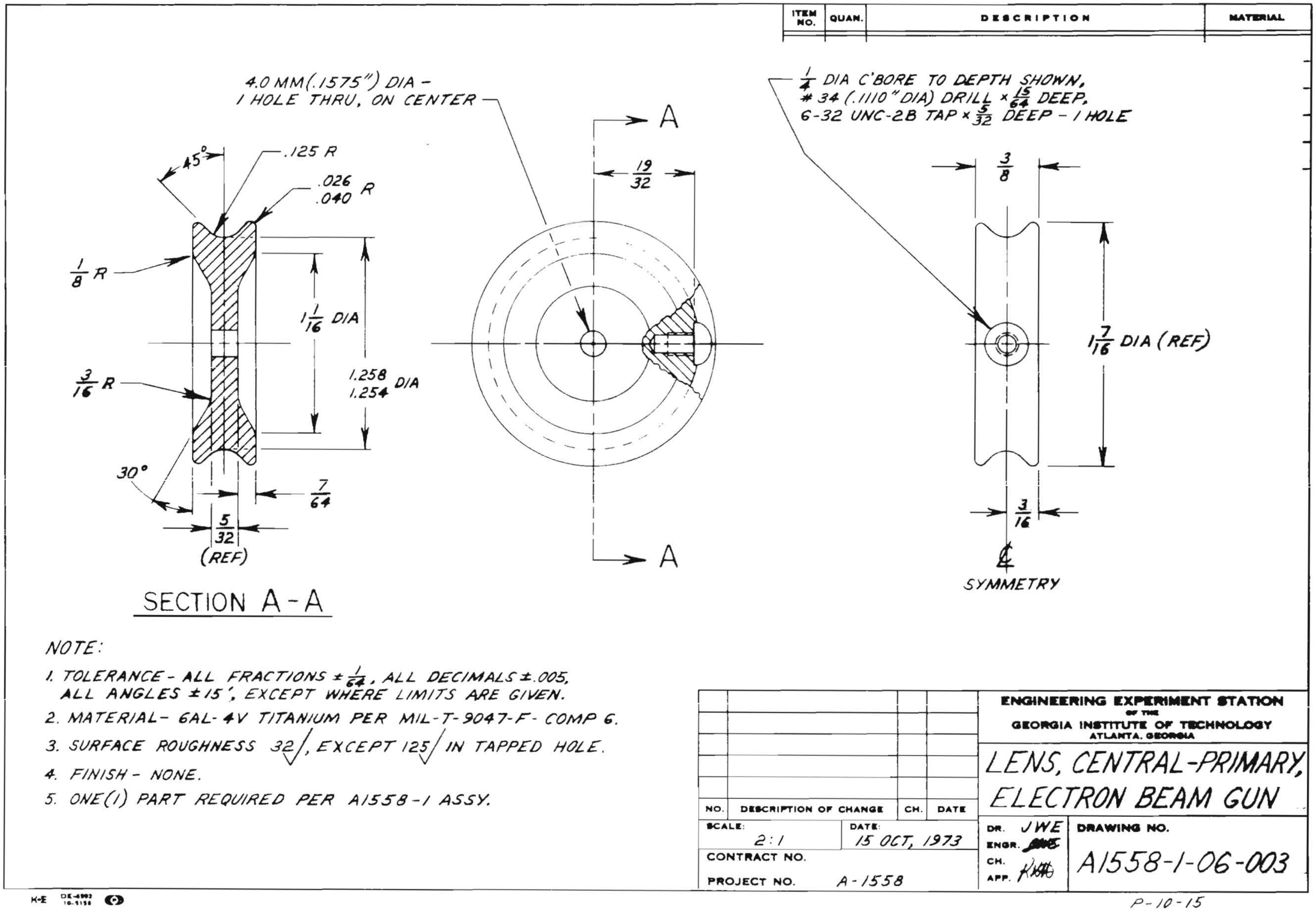
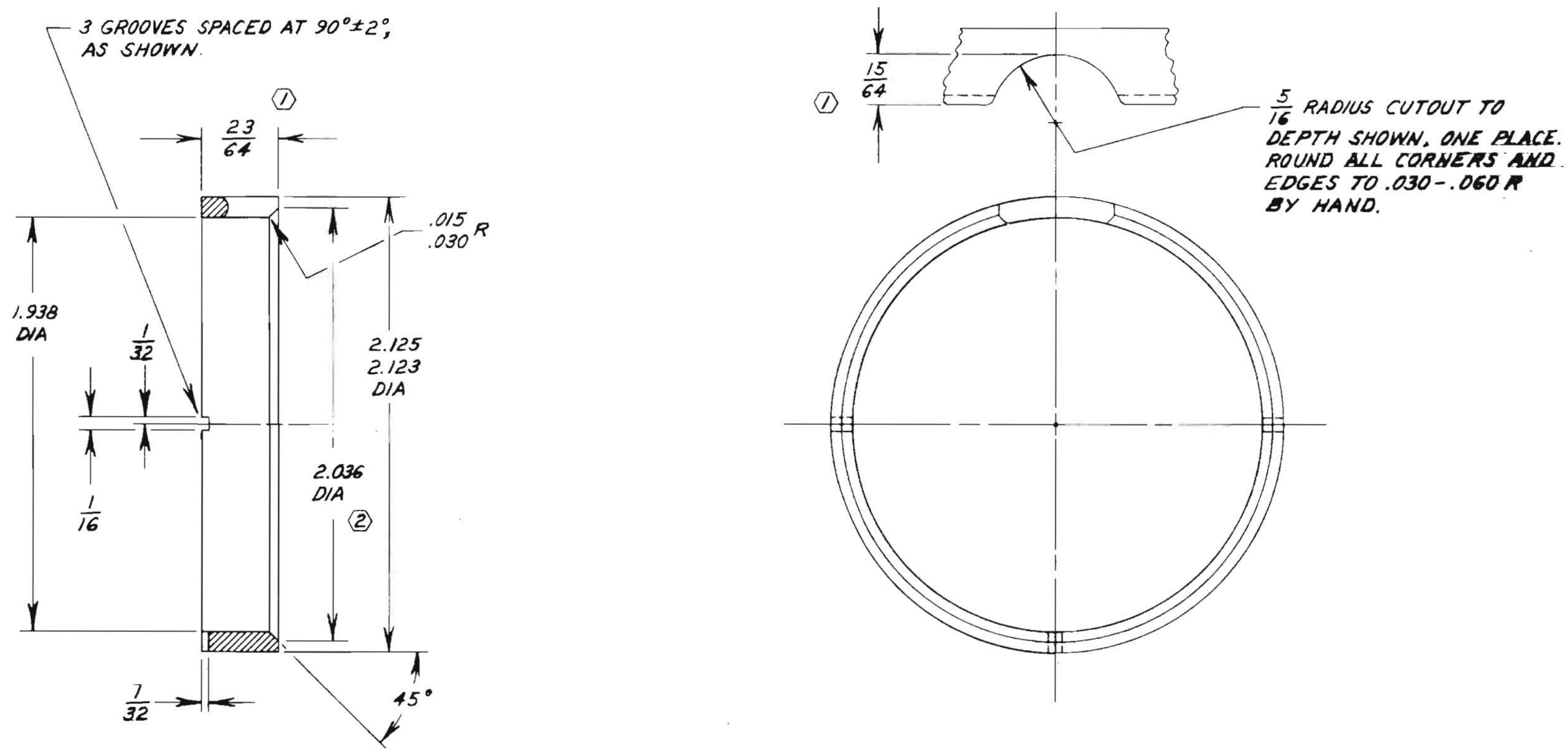


Fig. A49. Center electrode-lens No. 1.



NOTE:

1. TOLERANCE - ALL FRACTIONS ± 1/64, ALL DECIMALS ±.005, ALL ANGLES ±15', EXCEPT WHERE LIMITS ARE GIVEN.
2. MATERIAL - TYPE 304 STAINLESS STEEL SEAMLESS TUBE.
3. FINISH - NONE
4. TWO (2) PARTS REQUIRED PER A-1558-1 ASSY.
5. SURFACE ROUGHNESS 63

NO.	DESCRIPTION OF CHANGE	CH.	DATE
2	ADDED 2.036 DIA	A	11/15/73
1	23/64 WAS 13/32, 15/64 WAS 9/32	A	11/15/73

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

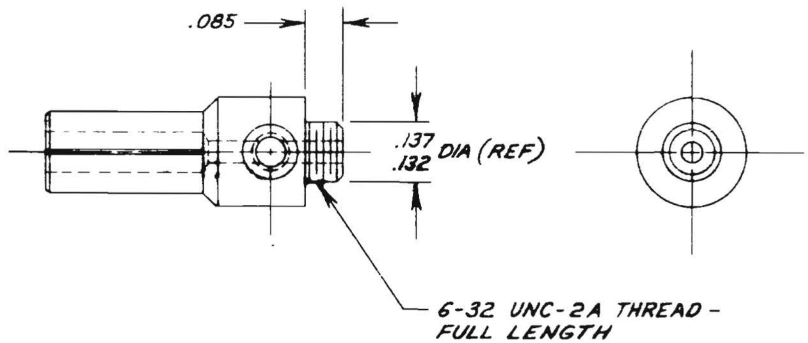
RETAINER, BALL-LENS, ELECTRON BEAM GUN

SCALE: 2:1	DATE: 24 OCT., 1973	DR. J. W. E. ENGR. JWE CH. APP.	DRAWING NO. A1558-1-06-004
CONTRACT NO.			
PROJECT NO. A-1558			

H-E DE 7556 10-8155

P-10-24-R-11-16

Fig. A50. Retainer, ball-lens No. 1.



NOTE:

1. TOLERANCE - DECIMALS ±.010 + NOTED.
2. FINISH - NONE.
3. TWO(2) REQUIRED PER A1558-1 ASSY.
4. MATERIAL - CERAMASEAL 890A7429-1 PUSH-ON CONNECTOR - BERYLLIUM COPPER.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

CONNECTOR-CENTRAL LENS,
ELECTRON BEAM GUN

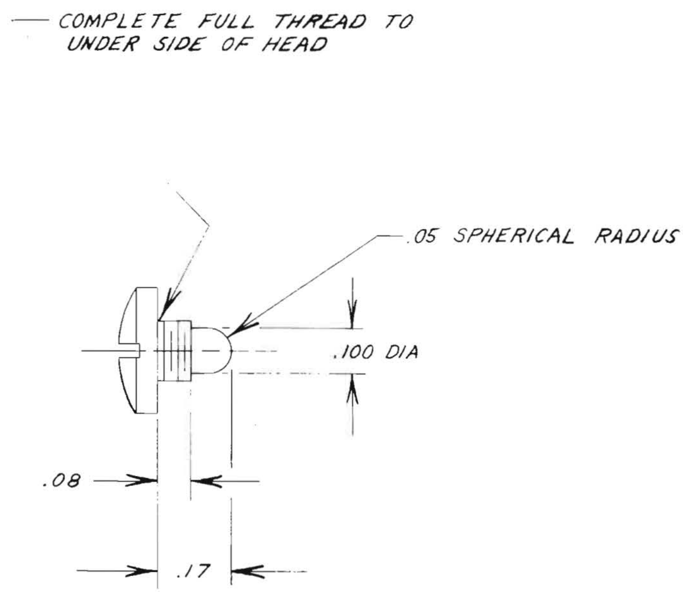
SCALE: 4:1	DATE: 24 OCT, 1973
CONTRACT NO.	
PROJECT NO.	A-1558

DR. J.W.E.	DRAWING NO.
ENGR. JWE	A1558-1-06-005
CH.	
APP.	

H-E DE 7884 10-8155

P-10-26

Fig. A51. Connector, center electrode-lens No. 1.



NOTE:

1. TOLERANCE - .XXX ± .005, .XX ± .010.
2. MATERIAL - SERIES 300 STAINLESS STEEL 6-32 UNC-2A BINDING HEAD SCREW.
3. FINISH - NONE
4. FOUR (4) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

SCREW, BALL STOP-LENS ASSEMBLY

SCALE: 4:1
DATE: 15 NOV., 1973
CONTRACT NO.
PROJECT NO. A-1558

DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-06-006

H-E DE 7556 10-5155

P-11-16

Fig. A52. Screw, ball stop-lenses No. 1 and No. 2.

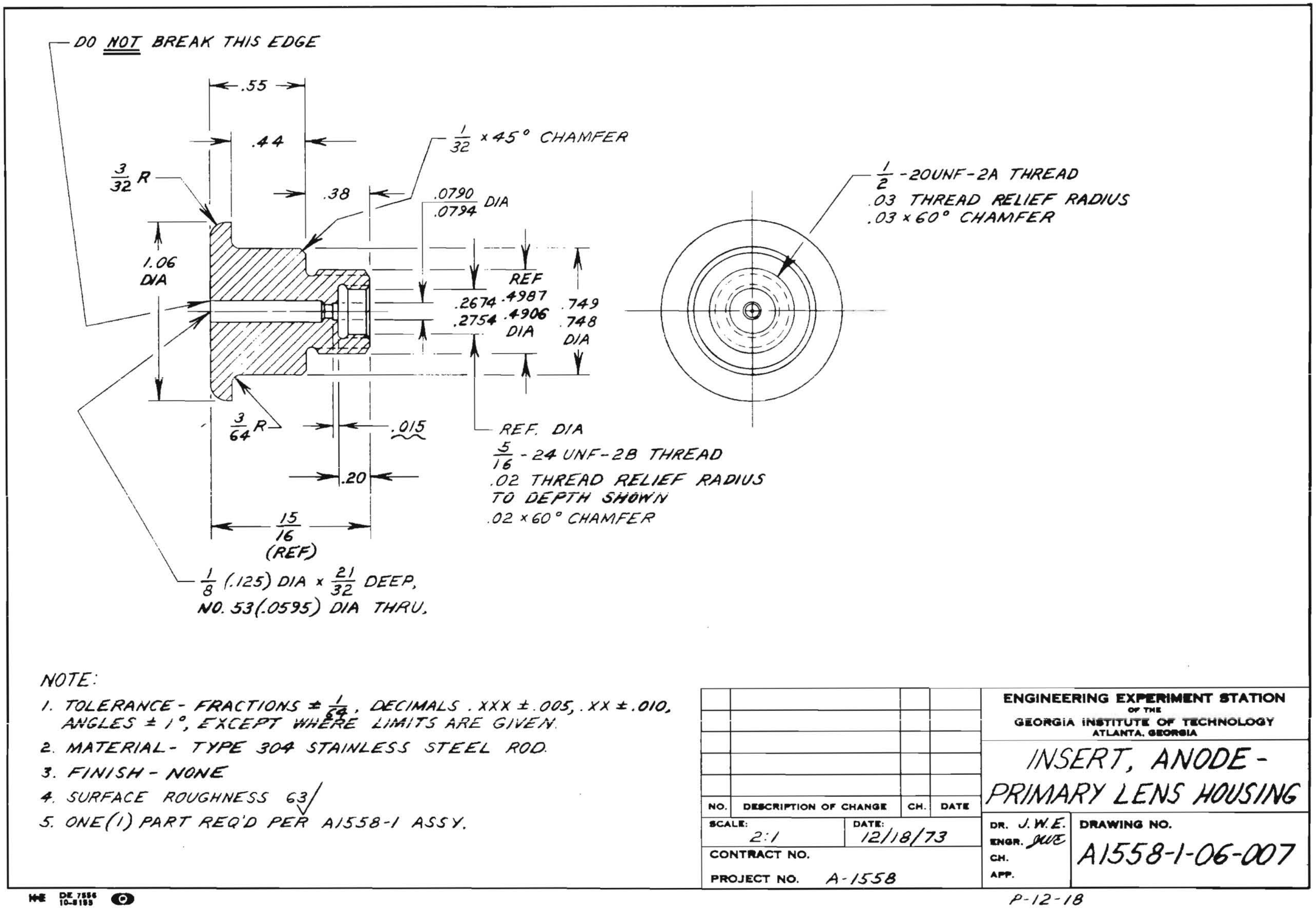


Fig. A53. Anode-lens No. 1 housing.

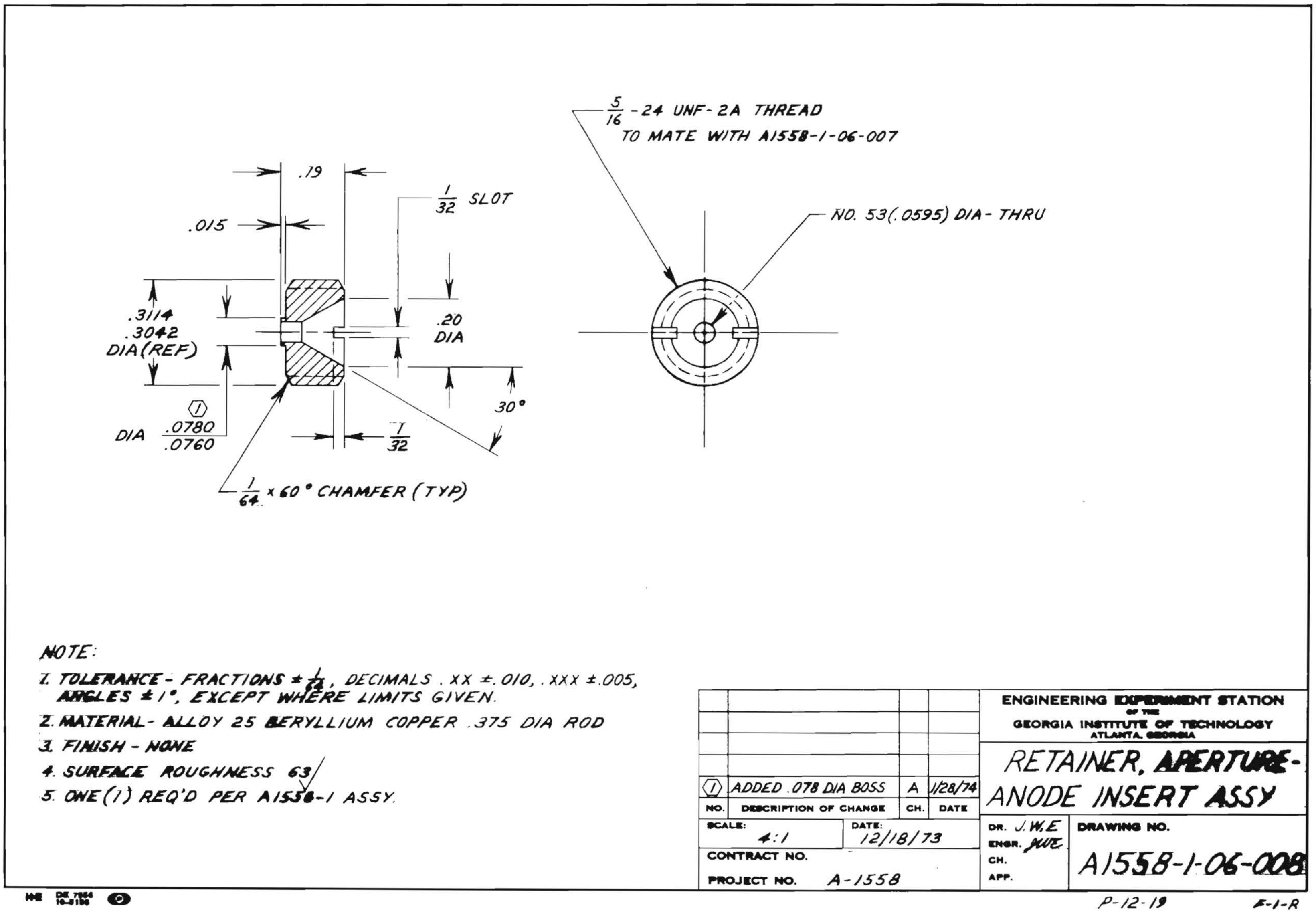
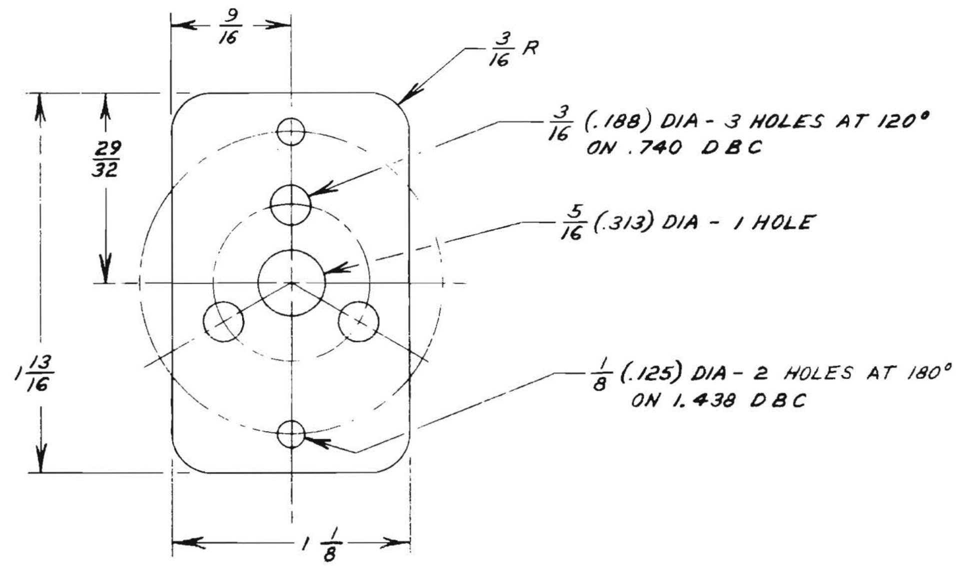


Fig. A54. Aperture retainer-anode.



NOTE:

1. TOLERANCE - FRACTIONS $\pm\frac{1}{64}$, DECIMALS $\pm$.005, ANGLES $\pm$15′
2. MATERIAL - .062 THICK, TYPE 304 STAINLESS STEEL SHEET
3. FINISH - NONE
4. ONE (1) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

RETAINER, STIGMATOR-
PRIMARY LENS ASSY

SCALE: 2:1	DATE: 12/21/73	DR. J.W.E	DRAWING NO.
CONTRACT NO.		ENGR. JWE	A1558-1-06-009
PROJECT NO. A-1558		CH.	
		APP.	

HE DE 7556 10-8155

P-12-21

Fig. A55. Retainer, stigmator-lens No. 1 housing.

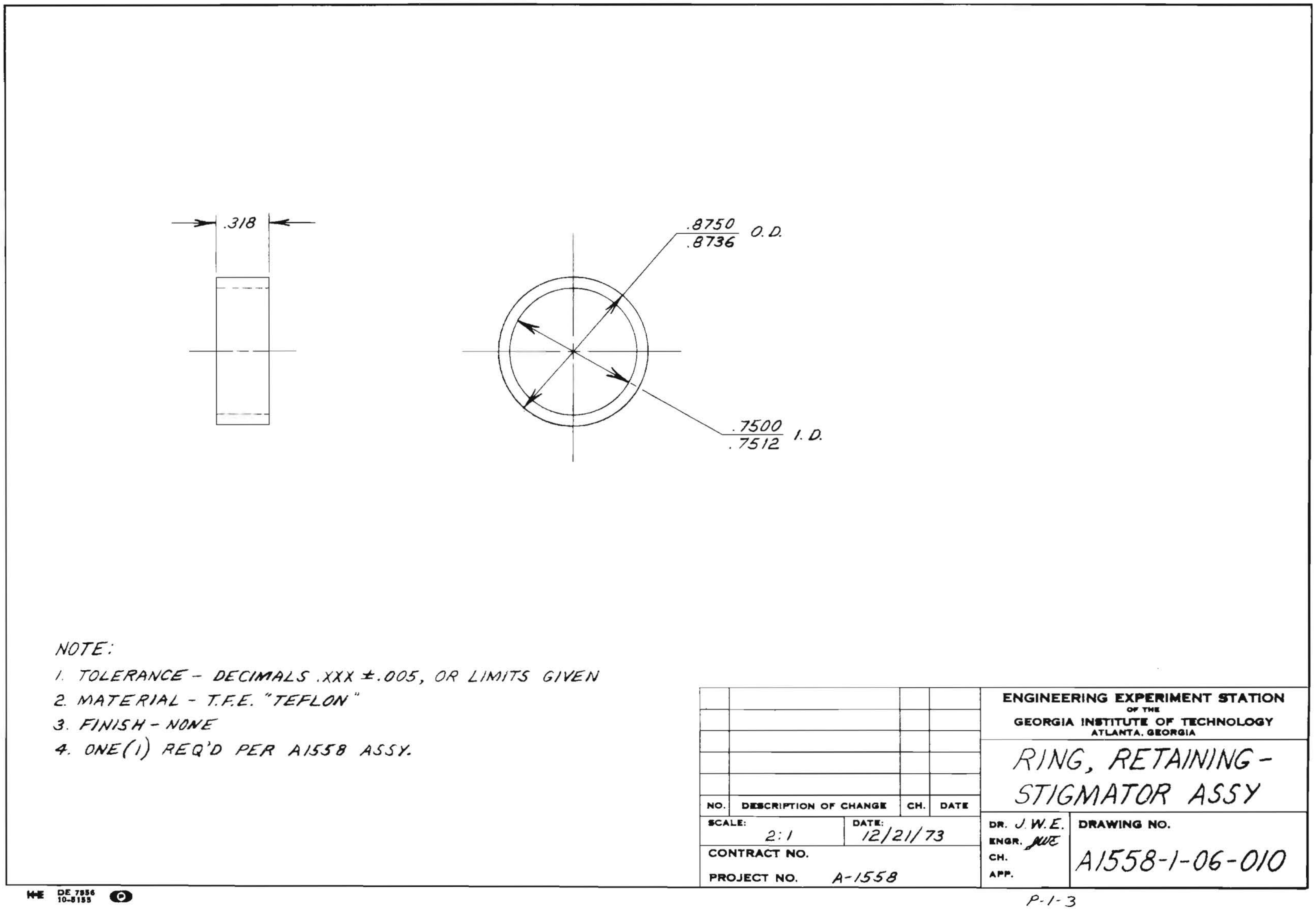


Fig. A56. Ring, retainer-stigmator.

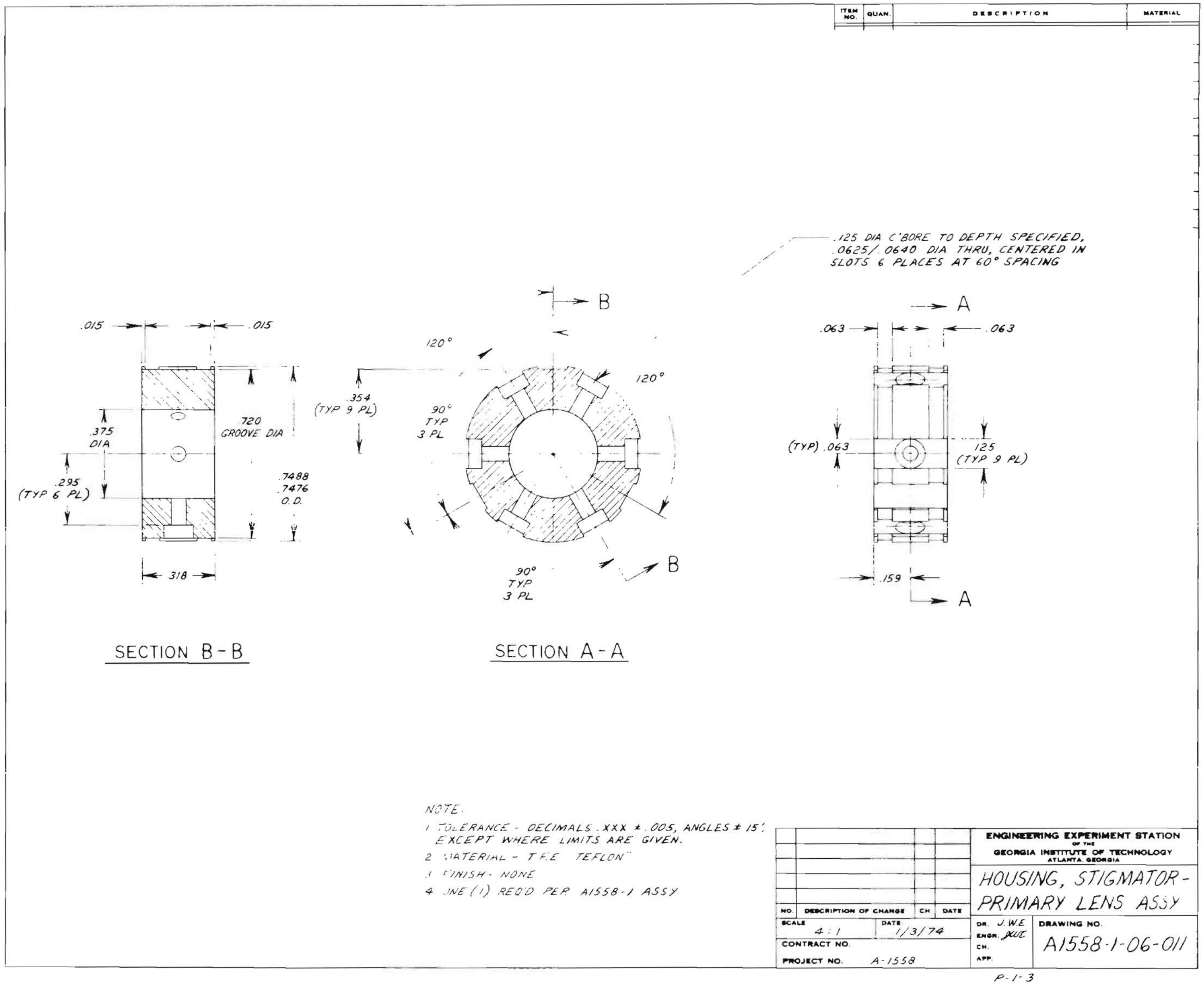
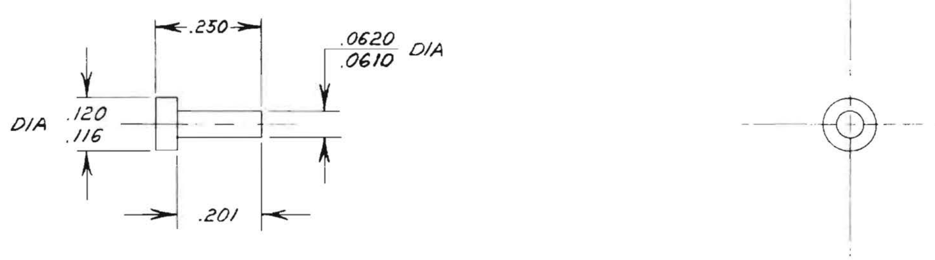


Fig. A57. Housing, stigmator-lens No. 1 housing.



NOTE:
1. TOLERANCE - DECIMALS ±.005, AND NOTED
2. MATERIAL - ALLOY 25 BERYLLIUM COPPER ROD
3. FINISH - NONE
4. SIX (6) REQ'D PER A1558-1 ASSY.

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

PIN, STIGMATOR - PRIMARY LENS ASSY

SCALE: 4:1 DATE: 1/3/74
CONTRACT NO.
PROJECT NO. A-1558

DR. J.W.E.
ENGR. JWE
CH.
APP.

DRAWING NO. A1558-1-06-012

DE 7556 10-5155

P-1-3

Fig. A58. Pin-stigmator.

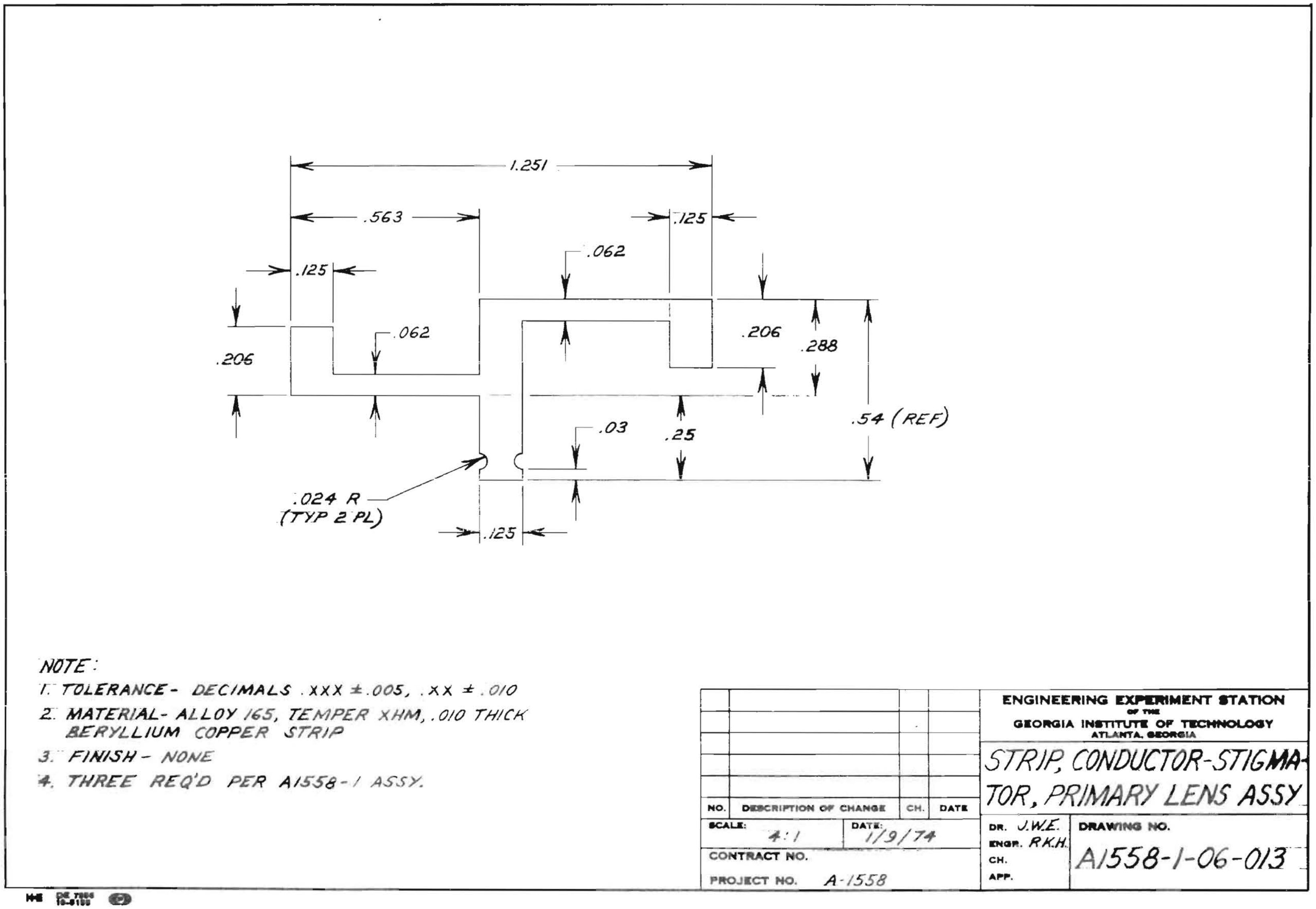


Fig. A59. Electrical conductor-stigmator.

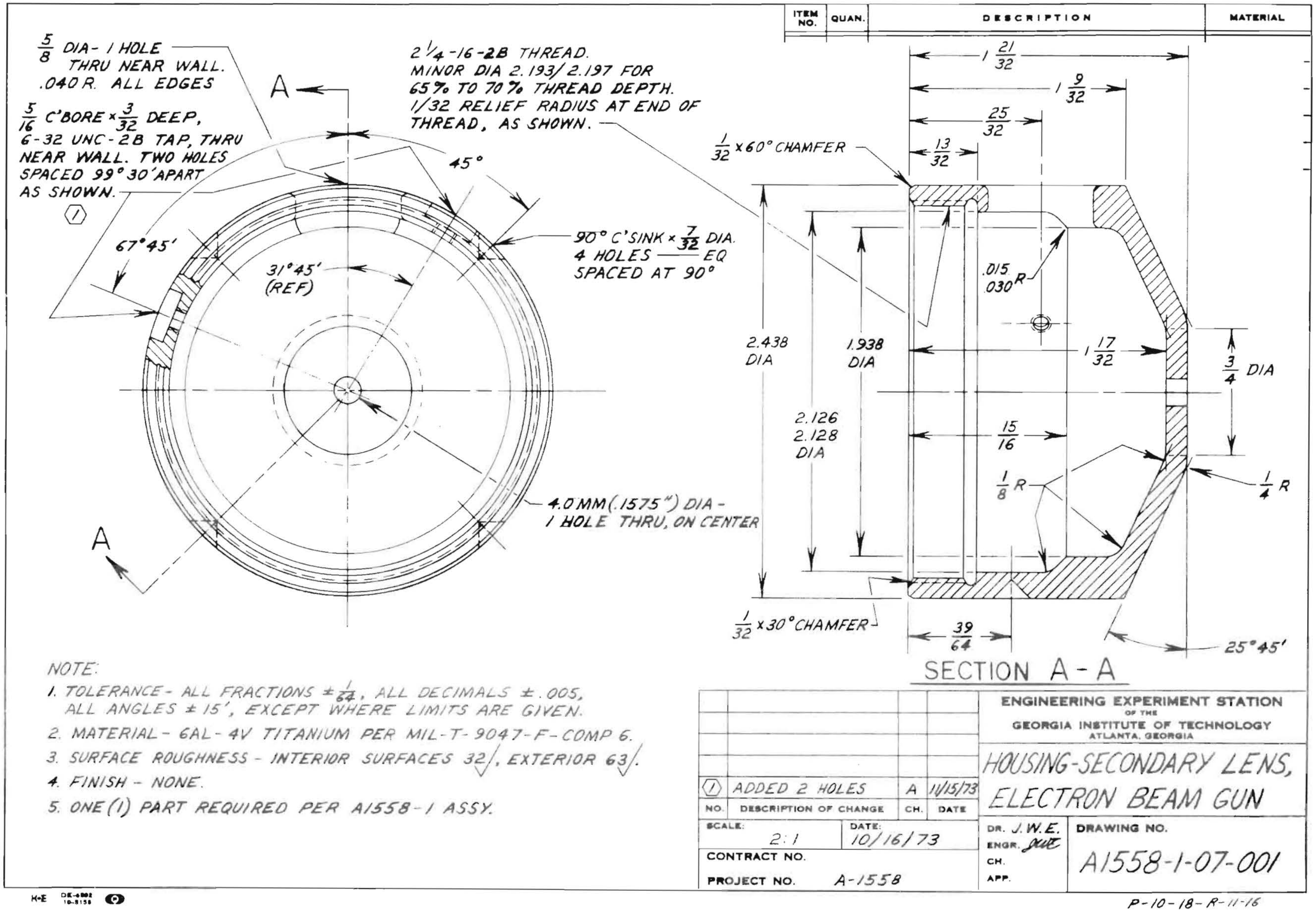


Fig. A60. Housing-lens No. 2.

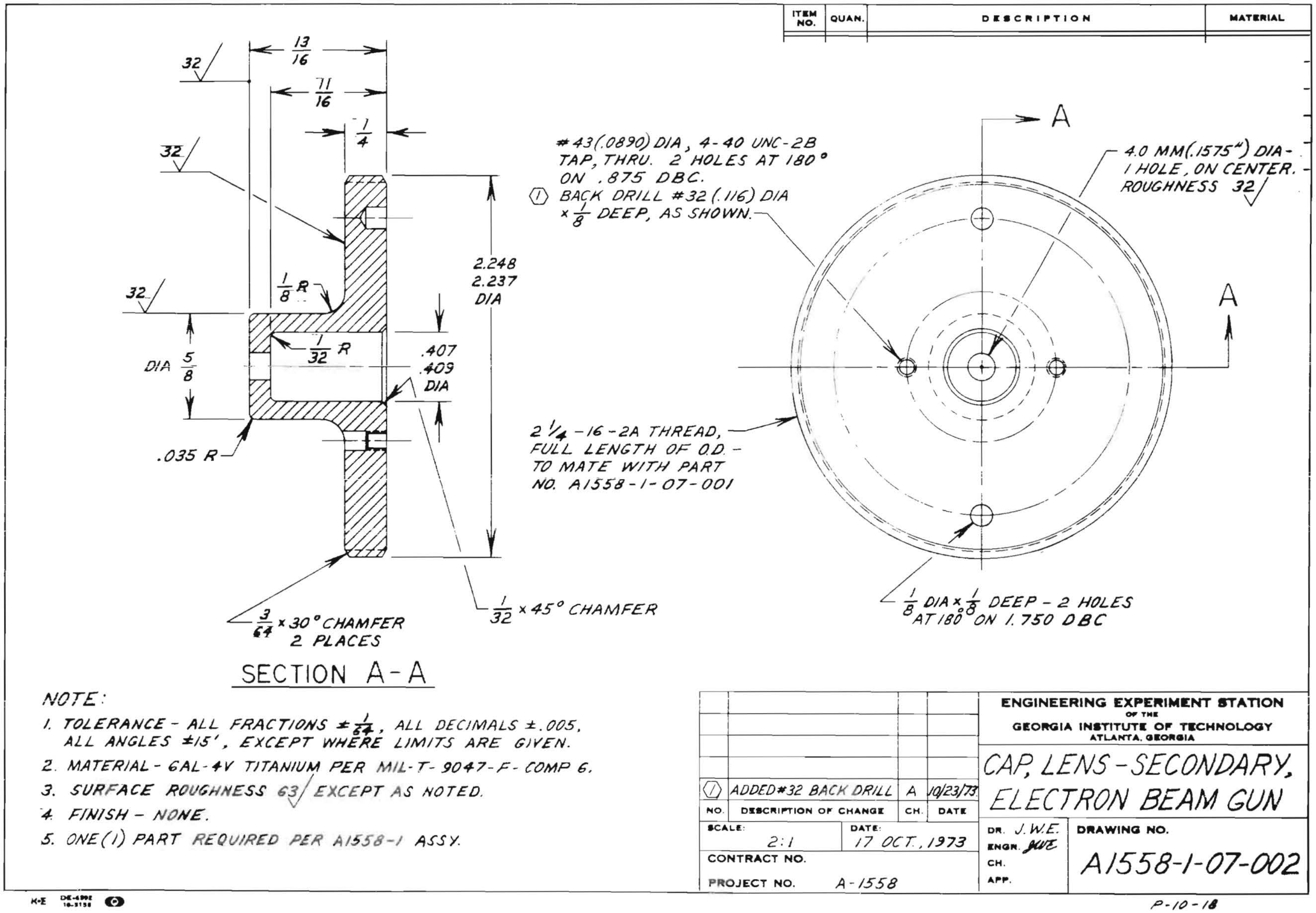


Fig. A61. Cap-lens No. 2.

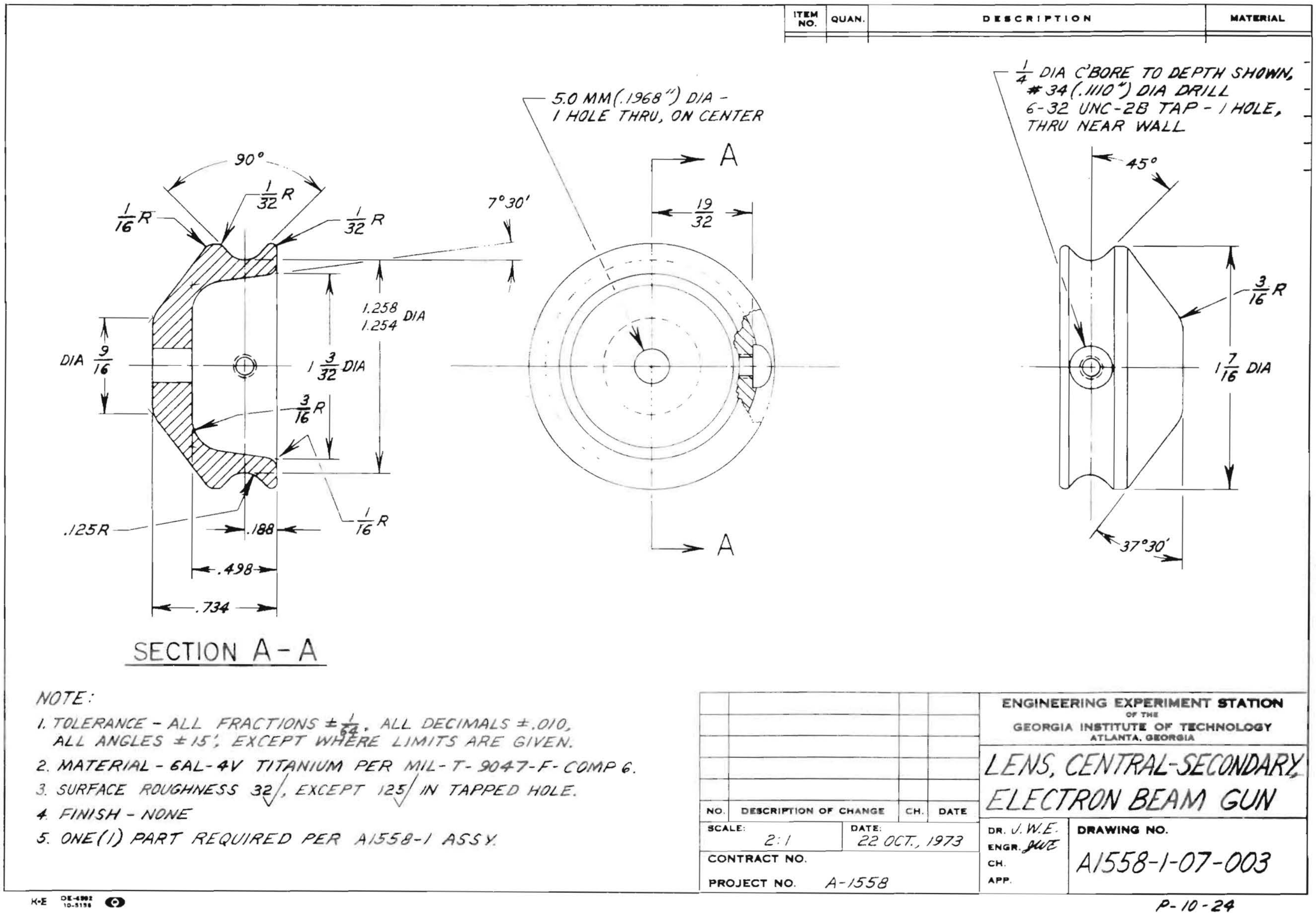


Fig. A62. Center electrode-lens No. 2.

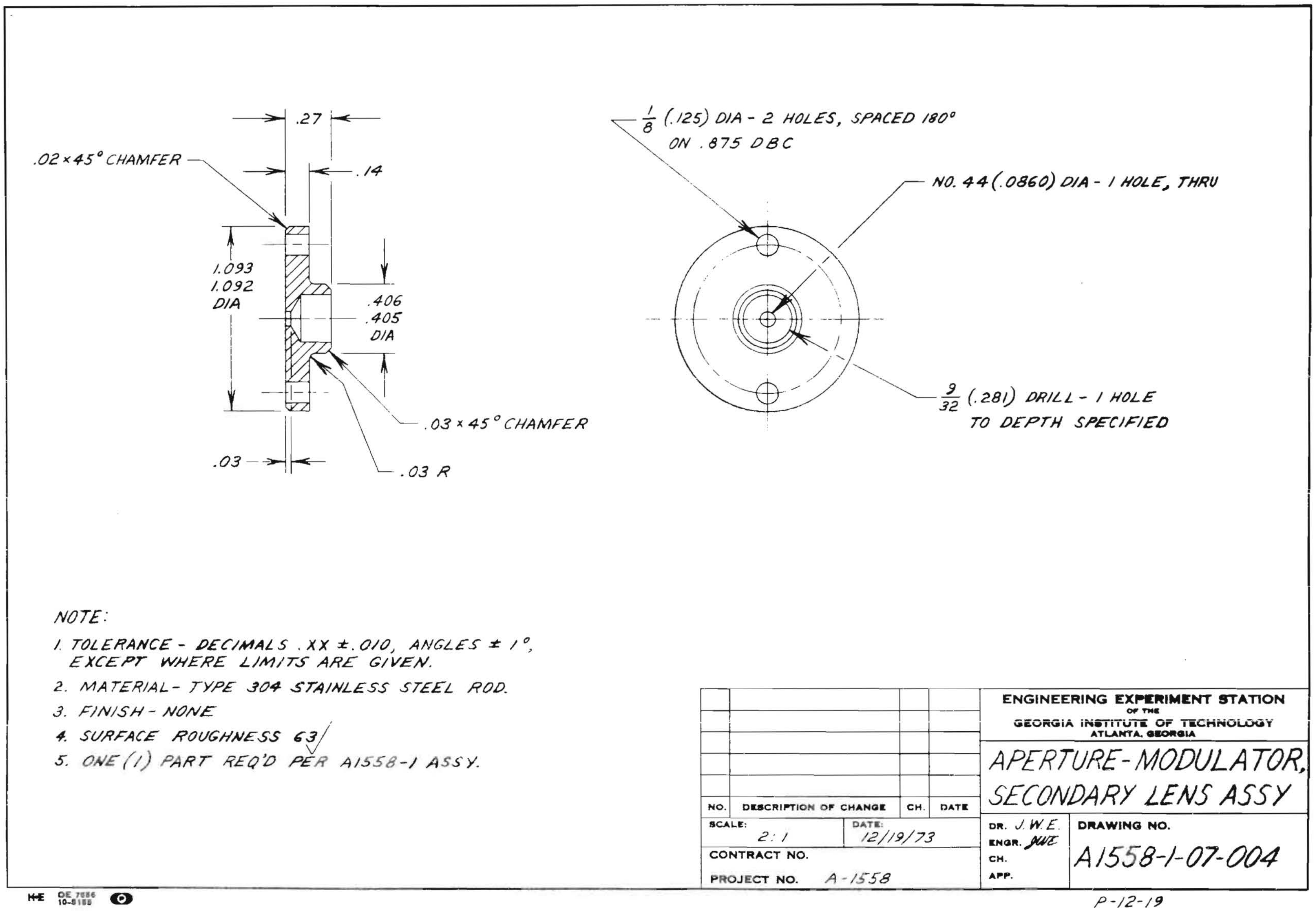


Fig. A63. Aperture-modulator.

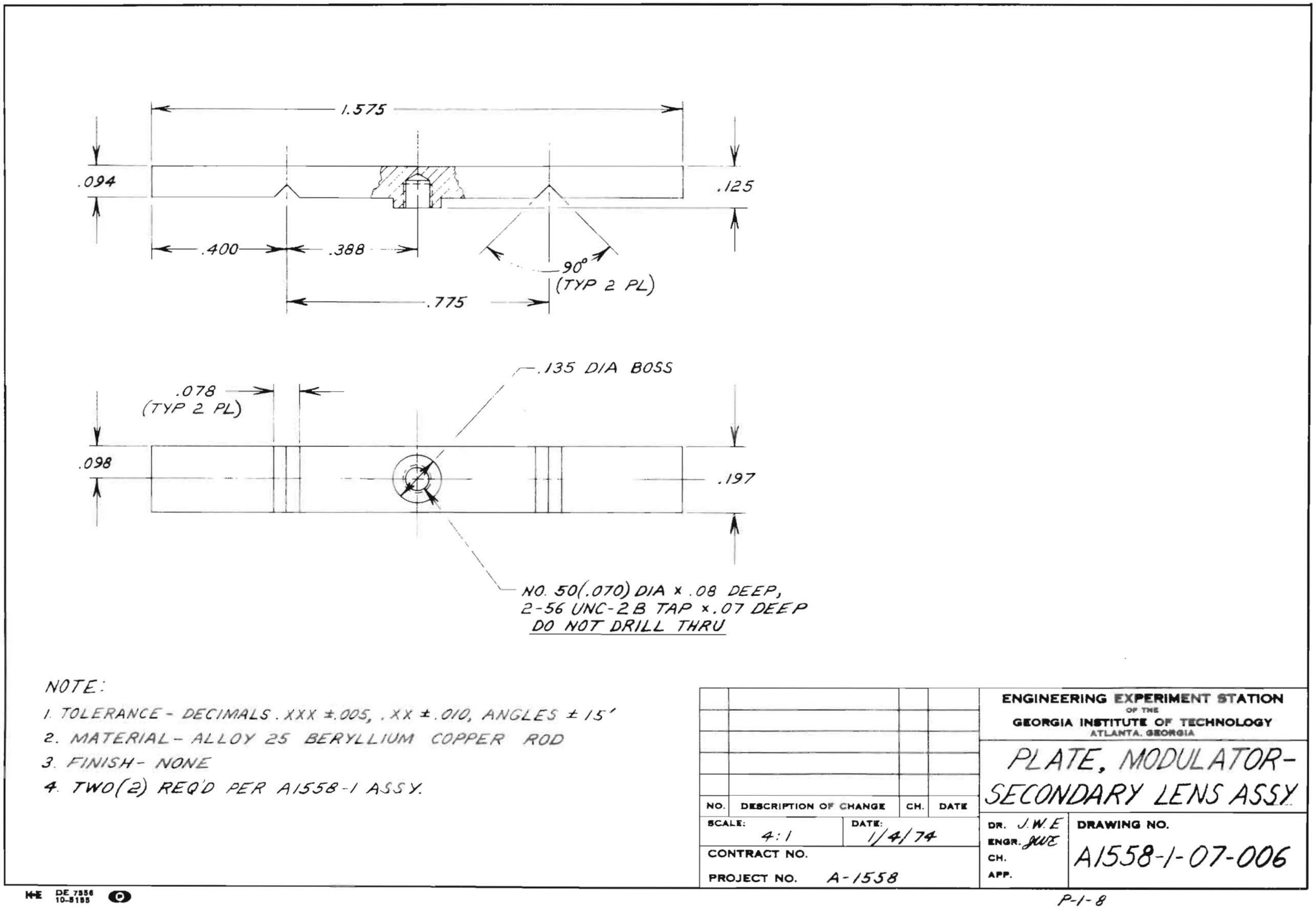


Fig. A65. Plate-modulator.

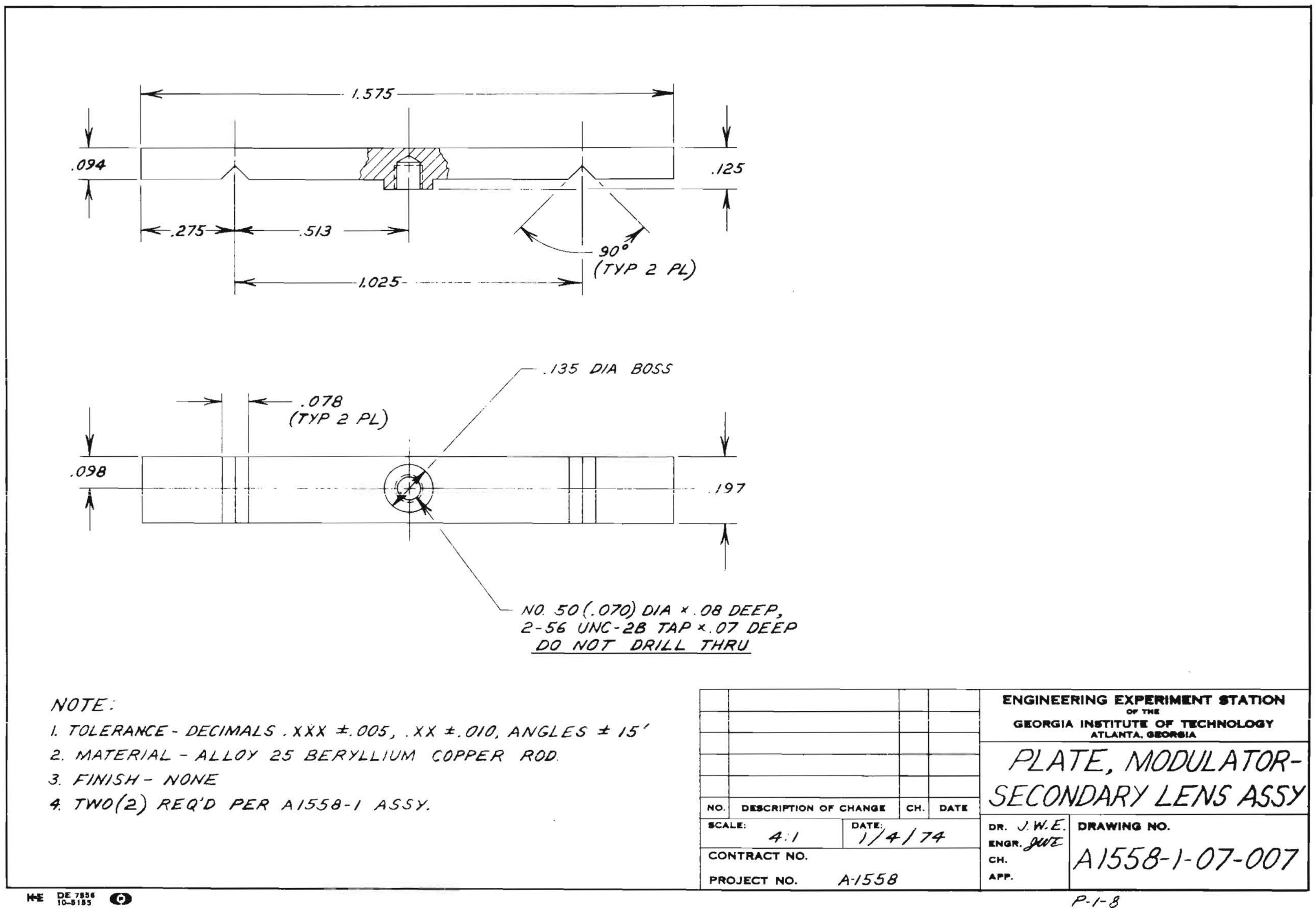


Fig. A66. Plate-modulator.

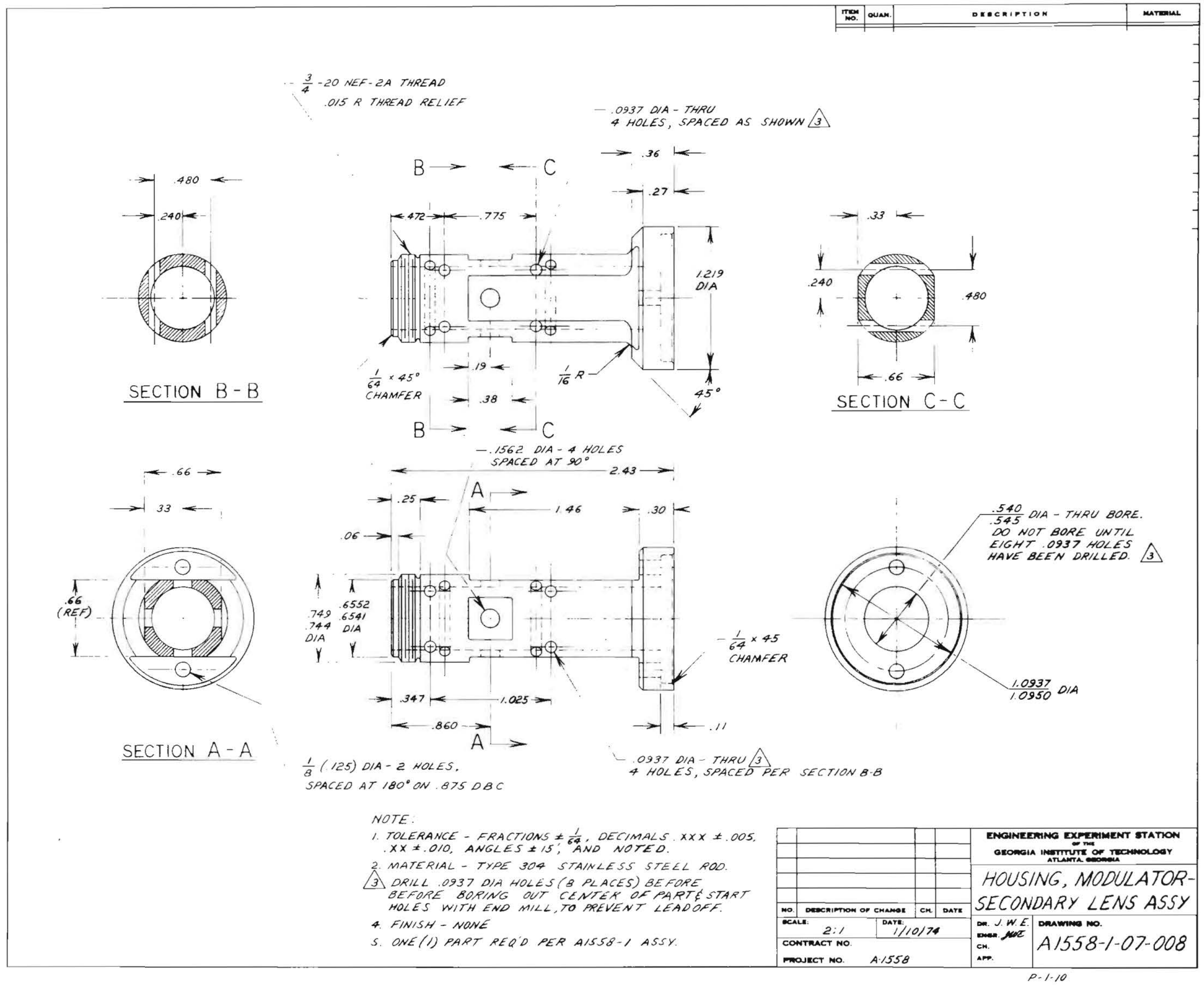


Fig. A67. Housing-modulator.

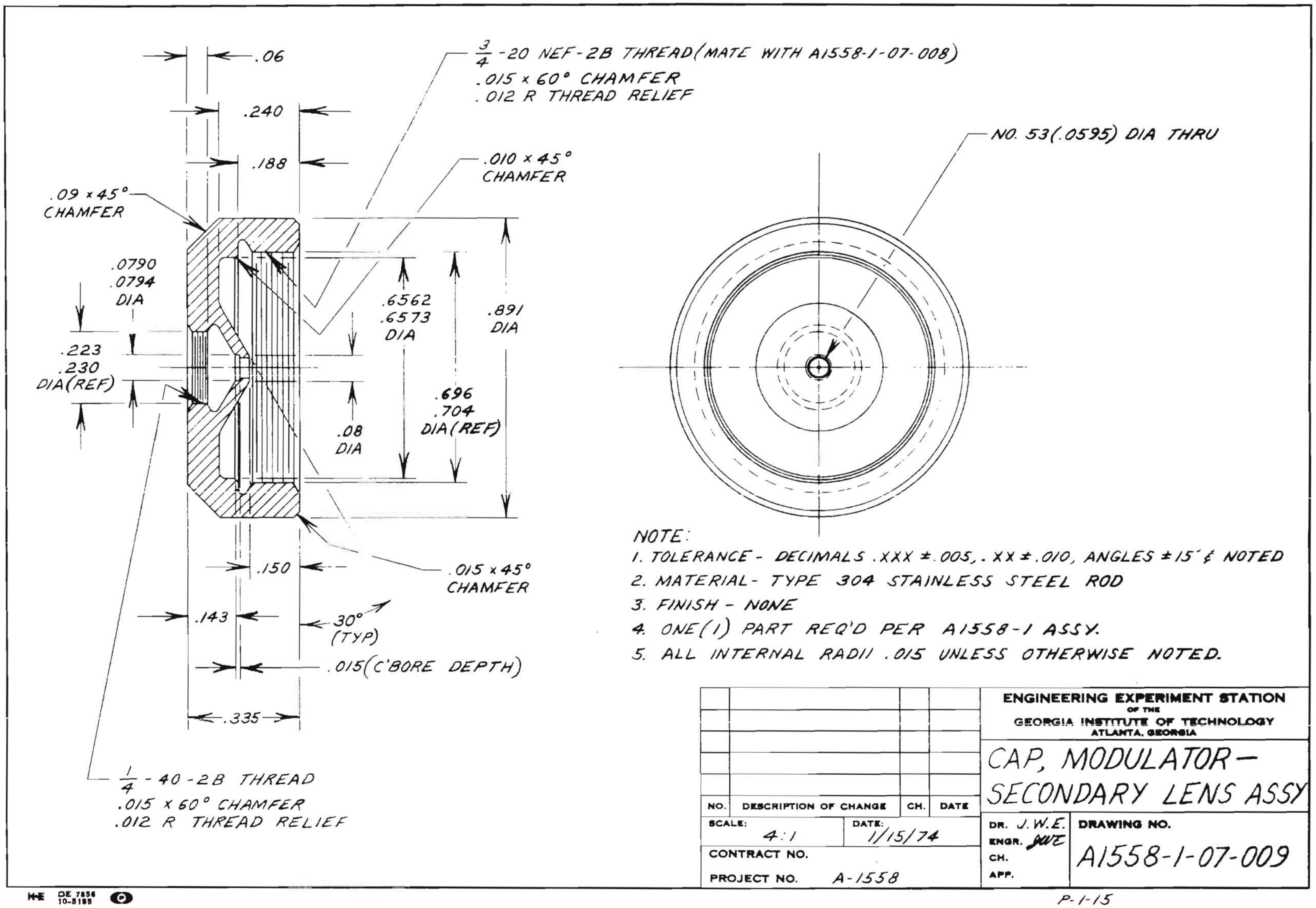


Fig. A68. Cap-modulator.

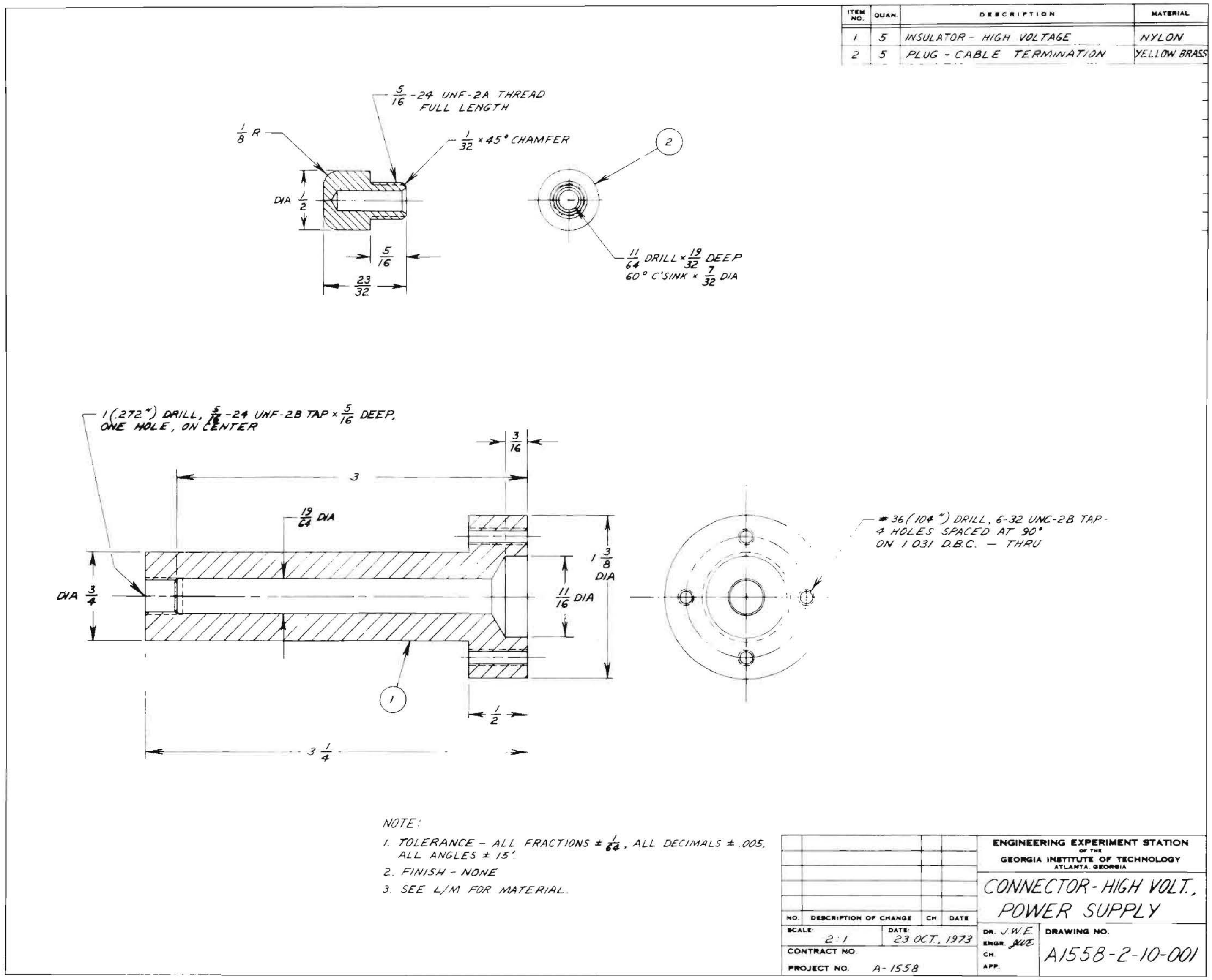
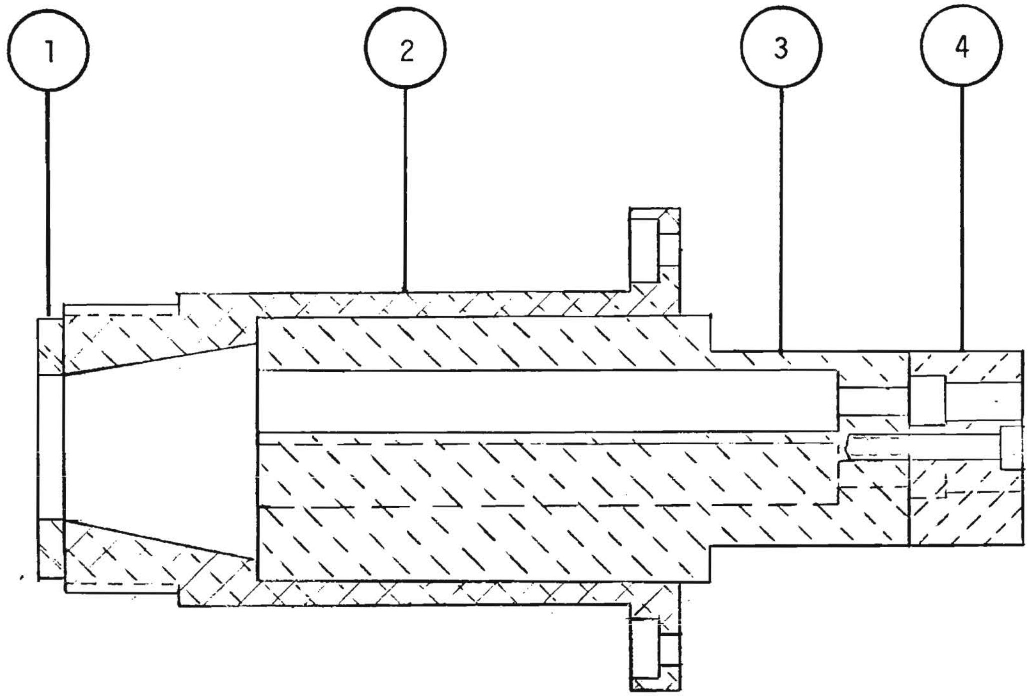
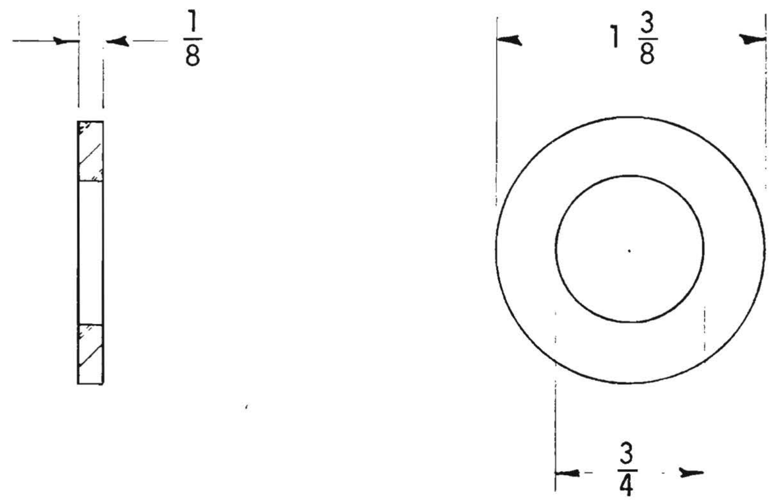


Fig. A69. Connector-electron gun control.



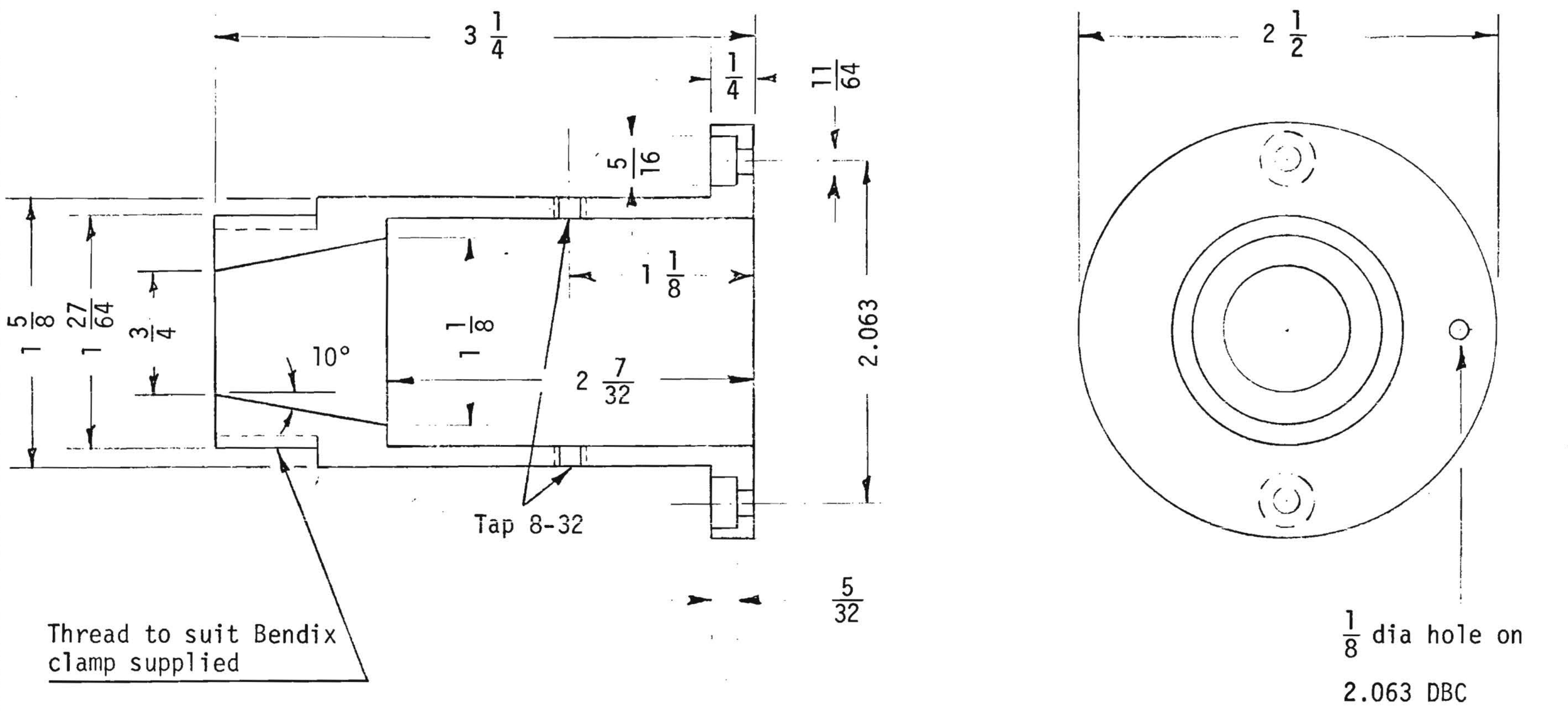
GEORGIA TECH	MAT'L.		Drawing No. A1558-2-20
DRAWN R. K. HART 12/12/73	SCALE 1:1	NO. REQ'D. 1	PART HIGH VOLTAGE PLUG ASSEMBLY

Fig. A70. Assembly-high voltage plug.



GEORGIA TECH	MAT'L. BRASS		DRAWING NO. A1558-2-20-001
DRAWN R. K. HART 12/12/73	SCALE 1:1	NO. REQ'D. 1	PART WASHER-HIGH VOLTAGE PLUG

Fig. A71. Washer-high voltage plug.



GEORGIA TECH	MAT'L. 6061 ALUMINUM		DRAWING NO. A1558-2-20-002
DRAWN R. K. HART 12/12/73	SCALE 1:1	NO. REQ'D. 1	PART HOUSING-HIGH VOLTAGE PLUG

Fig. A72. Housing-high voltage plug.

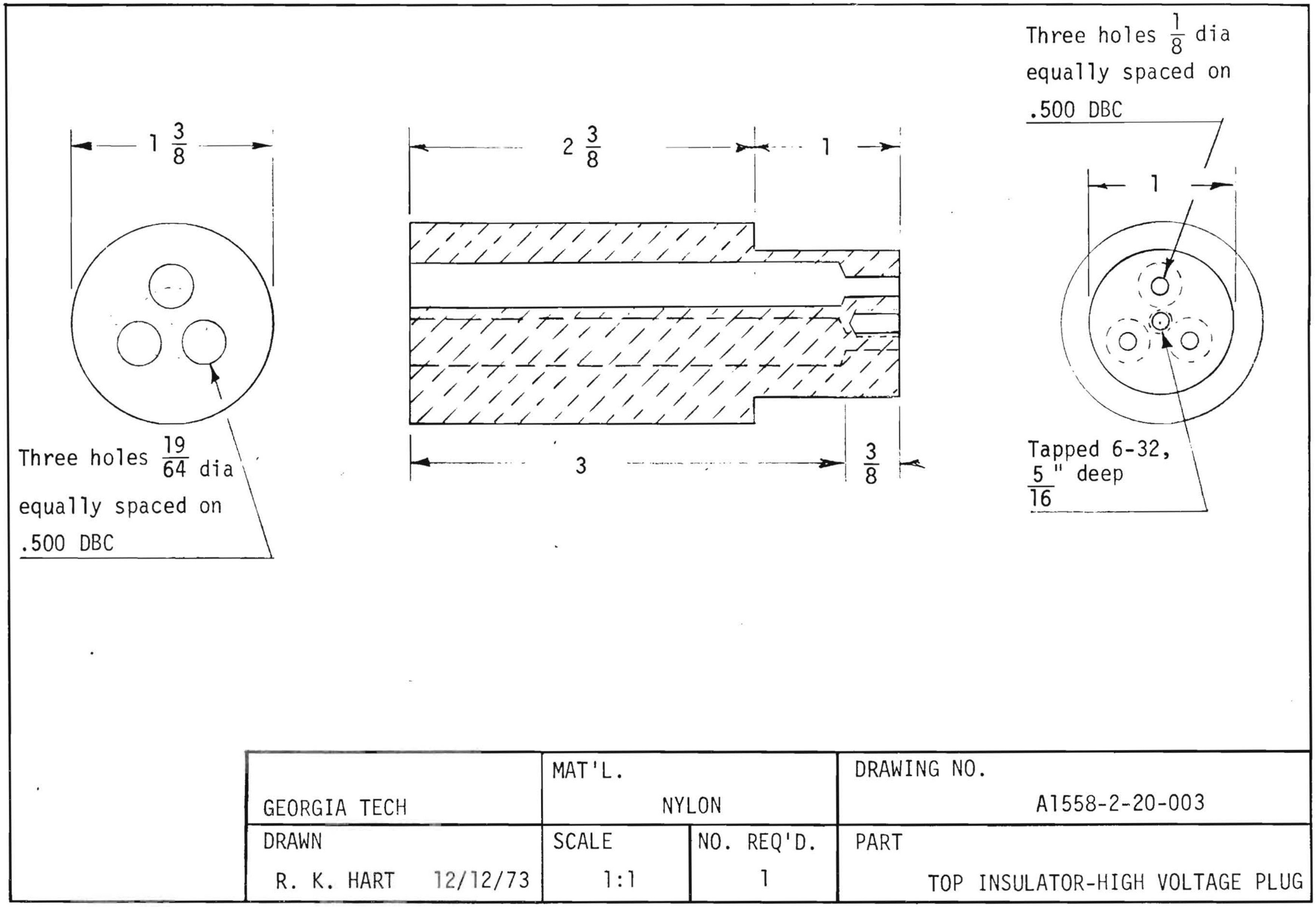
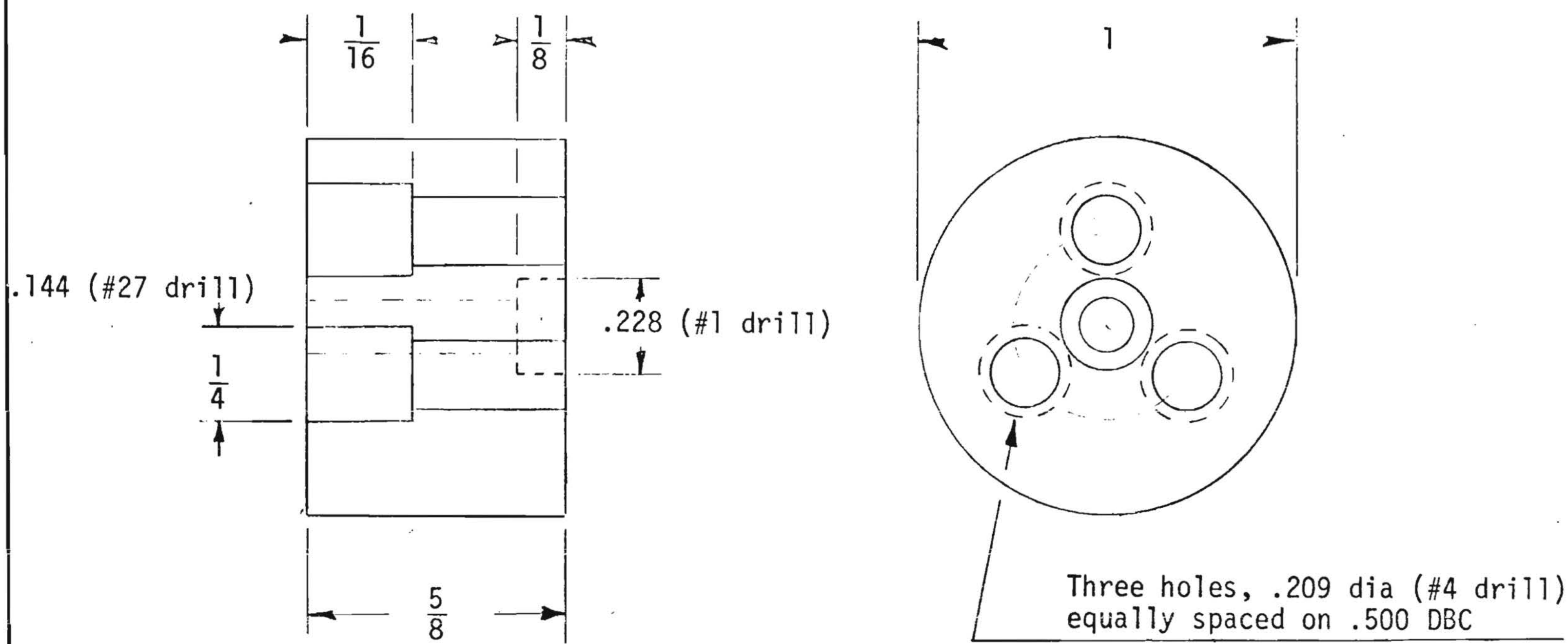


Fig. A73. Top insulator-high voltage plug.



GEORGIA TECH	MAT'L. NYLON		DRAWING NO. A1558-2-20-004
DRAWN R. K. HART 12/12/73	SCALE 2:1	NO. REQ'D. 1	LOWER INSULATOR-HIGH VOLTAGE PLUG

Fig. A74. Lower insulator-high voltage plug.